The Technique of

PULMONARY RESECTION

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Revised Second Printing

By

RICHARD H OVERHOLT, M D ,

Clinical Professor of Surgery Tufts College Medical School Surgical Staff Member of the New England Deaconess Hospital The Faulkner Hospital and the Joseph H Pratt Diagnostic Hospital Boston Massachusetts Consultant Thoracic Surgeon to Belmont Bristol Barnstable Cambridge Essex Norfolk Sanatoria in Massachusetts and to the New Hampshire and Rhode Island State Sanatoria

and

LAZARO LANGER, M D ,

Instructor in Surgery University of Cordoba Service of Professor Juan Martin Allende Cordoba Argentina Former Fellow in Thoracic Surgery Rockefeller Foundation and the Thoracic Fund

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Dedicated

to

Present and Past

Thoracic Surgical Fellows

Foreword

MUCH OF THE SUCCESS of surgical therapy in prolonging life and restoring health has depended upon the principle of excision Tissue irreparably damaged or destroyed by infection, neoplasm, or injury may require removal if the host is to survive The individual not only suffers the loss of the tissue involved, but the economy of other organs may be threatened by a spread of the disease Sixty years of application of excisional therapy in abdominal disease have established this principle firmly Advances in all branches of medical science have not changed the fundamental concept of salvaging the host by excision of the organ containing the life threatening disease. Since man also falls prey to potentially fatal diseases which destroy lung tissue, there is a real need for a program of therapy, the goal of which is lung resection

Surgeons working in the thoracic field have found it necessary to become individual pioneers Often they have worked without benefit of text, atlas, or a system of surgical practice dictated by wide experience Books on thoracic surgery are few and most antedate the era of visceral thoracic surgery The contributions on technical matters pertaining to lung resection which have appeared during the past fifteen years have been included, for the most part, with a discussion on disease entities such as pulmonary cancer, bronchiectasis, chronic abscess, or tuberculosis They have not dealt solely with details of exploration and dissection or with plans for every type of resection that confronts the thoracic surgeon

The first part of this book takes up technical matters that are common to any type of resection Preparation, anesthesia, exposure, exploration, and planning the extent of the resection, together with general principles of dissection, treatment of the various elements of the lung, and closure are considered

The second part of this book considers in some detail the anatomy of the lung itself as it applies to problems of dissection at the primary, secondary, and tertiary hilar levels. A thorough knowledge of the surgical anatomy of the bronchovascular pulmonary segments is necessary if the surgeon is to be free to make that choice of resection most ideally suited to each individual pathological process from the standpoint of safety, permanency of control, and functional conservation. Each specific type of resection is then considered. The removal of either lung is described, then the excision of the various lobes, and finally the resection of the bronchopulmonary segments

The last chapters deal briefly with problems of postoperative care and management of complications A consideration of delayed post-resection thoracoplasty and the techniques involved is included.

Since this book is limited largely to technical matters of resection, we have purposely omitted several related subjects A discussion of disease entities which require pulmonary resection for their successful treatment has not been included. A description of essential diagnostic tests and procedures has also been omitted. Reference has not been made to available methods of detecting intrathoracic disease at an early and favorable time for treatment

The history of pulmonary resection is such a new chapter in the development of thoracic surgery that most facts are fresh in the mind of the reader Historical data has therefore been omitted

This book is primarily a presentation of the technique of resection as used by the authors. Reference is made to alternate steps that we occasionally find to be helpful. It seemed unwise to burden the reader with references to methods recommended by other surgeons as these are available in the literature It is believed that many of the practices which we have adopted are also standard practices of other surgeons No particular claim of originality is made for most of the steps which are described Two new technical advances which were originally developed in our clinic are included

and seem to us important The prone position of the patient during the operative manipulation, with the diseased lung maintained in a dependent position, has been of great help to us in carrying out all types of resection The second original idea concerns an atraumatic and precise technique of dissection of the intersegmental plane which permits the removal of a segment without the use of clamps This method allows one to use the segment as a surgical unit with greater freedom rather than the lobe, provided the disease is so limited

It is our purpose to set forth in a convenient and usable form our own accepted practice of removing segments, lobes, or an entire lung Every surgeon, through reading, observation, and practice develops his own style and method which, for him, produce the best results There is no end point of perfection, so surgical practice is always a changing panorama of shifting detail This work is undertaken with the full knowledge that by the time this book is published certain details of procedure will have been discarded and others added However, there are basic and fundamental principles many of which are known and these will not change It is our hope that a well illustrated description of our current approach to the problem of lung resection will be helpful to students and thoracic surgeons

Practices in surgery are influenced by many tangible and intangible factors Countless individuals have contributed Not only does the success of any operation depend upon a highly integrated team but basic concepts of how that team can best function evolve from suggestions, criticisms, and discussions from many sources

Assistants most intimately associated with a surgeon over long period of time influence his work to the greatest degree Our first acknowledgment and thanks go to those who received training in thoracic surgery during this developmental period of excisional pulmonary surgery Dr Reeve H Betts Dr John S Harter, Dr Oswald S Tubbs, Dr William Ray Rumel, Dr Bert H Cotton, Dr Emil A Naclerio, Dr Norman J Wilson, and Dr John T Szypul

ski Much help in a more direct way has been given by Dr. Reeve H. Betts and Dr. Francis M. Woods who have gone over the manuscript and have made valuable suggestions as to content and presentation To them we are grateful.

We are also indebted in no small measure to the artists, Miss Etta Piotti and Miss Evelyn Olsen who have skillfully worked long hours to portray technical steps, and to Mr. Sherman Atwell who did the photography. The editing of the manuscript has been the work of Miss Helen Adams and for taking over this task we extend to her our thanks

RICHARD H OVERHOLT, M.D

LAZARO LANGER, M.D.

CONTENTS

CHAPTER 1

Pre operative Preparation

PULMONARY RESECTION is an elective procedure in almost all instances Sufficient time may, therefore, be taken to make certain that the patient is brought up to his best possible physical state Certain patients are confronted with the necessity for resection when other systems are in balance, and the general state of the health is reasonably good How ever, many thoracic diseases, serious enough to demand re section, attack the individual in the later decades of life (cancer), or are of such a nature that other systems have already been seriously handicapped This is particularly true when suppuration is present (lung abscess, bronchiectasis, or infection superimposed upon cancer) Prolonged periods of bed rest and complications in other forms of treatment are also factors which undermine the general physical status of patients requiring resection This applies particularly to complicated forms of tuberculosis

All of the known supportive measures which are used in the preparation of patients for any type of major surgery apply in this field These are well known and need not be elaborated upon here It should be emphasized, however, that in long standing cases of chronic pulmonary suppura tion, severe forms of secondary anemia and hypoproteinemia are often encountered Then, obviously, replacement therapy is indicated and essential A diet rich in carbohydrates and protein should be given with vitamin and iron supplements Pre operative treatment by venoclysis in the form of amino acids, plasma, and whole blood will do much to restore proper protein levels

Added to consideration of the constitutional state of the

patient before operation are particular problems which pertain to the disease process itself within the lung that require pre-operative treatment. These have to do with the element of infection and with respiratory function.

THE ELEMENT OF INFECTION

Infection enters the picture in four common conditions for which lung tissue is resected: chronic abscess, bronchiectasis, and malignancy or tuberculosis with associated pyogenic infection Chemotherapeutic drugs, principally the sulfa compounds, have been of great service and still may be used in isolated instances to reduce the severity of infection prior to resection. The antibiotics have proved to be even more effective and helpful. Penicillin has had wide clinical use and its effect on respiratory infections is well known. Reported experimental work and the early clinical trials of streptomycin indicate that it, too, will eventually be useful in clearing up or reducing the severity of pulmonary infections caused by certain gram-negative organisms Fortunately, both these antibiotics may be administered in two ways to combat intrapulmonary infections, systemically by intramuscular injection and directly via the bronchial system by inhalation

Pre-operative Penicillin—At the present time penicillin is administered routinely in the preparation of those patients for resection in whom there is any evidence of respiratory or bronchial infection The patient inhales the nebulized drug, 20,000 units dissolved in 0 5 cc normal saline, every three hours during the waiting period. A glass nebulizer connected to a tank of oxygen or compressed air is used. The solution is nebulized by the passage of the gas at four to five liters per minute. A glass tube is placed in the rubber tube connecting the gas tank and nebulizer The patient closes his mouth about the mouthpiece during inspiration and inhales the fumes of penicillin The open end of the tube is closed by the forefinger of the patient during inspiration and the finger is removed during expiration. In this simple way the

flow of the gas is interrupted and the vaporization of the drug is stopped during the expiratory phase. The use of a rubber re breathing bag placed between the mouthpiece and nebulizer is somewhat more economical of the drug Most patients prefer not to re breathe in the apparatus and the simpler apparatus has been found to be of greater practical value (see Figure 1)

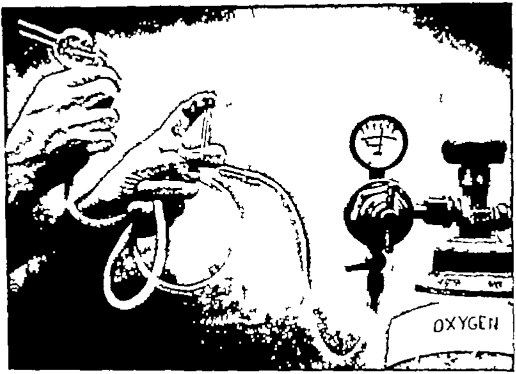


FIG. 1 Apparatus used for nebulization of penicillin or streptomycin The patient closes his lips on the mouthpiece and exhales through his nose The flow of gas is broken during expiration by finger control of the Y tube opening

If there is evidence of a systemic reaction to the pulmonary infection, the inhalation method of administration is supplemented by intramuscular injections of the drug The customary dosage of 15,000 Oxford units in 3 cc of saline is injected every three hours

The length of time over which treatment is continued varies considerably,—usually not less than three and rarely longer than fourteen days Soon, if the antibiotic is to be of

value, there will be noted a decrease in the amount and character of the sputum The sputum thins out and becomes less purulent in character If an odor was present, it frequently disappears The general condition of the patient is seen to improve with increased strength, weight gain, and better appetite

Streptomycin has not so far been extensively used by us in the pre-operative preparation of patients Reported experimental work and a limited clinical trial suggest that as this drug becomes commercially available and its cost not prohibitive, it may be used to great advantage if gram-negative organisms are present Patients with infections due solely to pathogens of known susceptibility to streptomycin may be prepared by the use of this drug alone It may be administered by nebulization as well as by intramuscular injection. Mixed infections of the respiratory system are so common that the nebulization of mixtures of antibiotics will in the future come to be most helpful in the preparation of patients for resection

IMPROVEMENT OF RESPIRATORY FUNCTION

If the respiratory function of the patient requiring resection is to be improved upon, it is quite obvious that the diseased segments themselves cannot be expected to contribute However, interference in the function of healthy segments can often be minimized, thus bringing about great improvement before operation The intimate connection of all pulmonary segments by the bronchial system results in a high degree of vulnerability of any segment to a reduced or total loss of function The flooding of the bronchial system with secretions in varied amounts and viscosities are the principal offenders Intermittent obstruction due to bronchospasm is another The entire bronchial system may be kept in a hyper-irritable state by disease in one part or by an associated generalized bronchitis Allaying the effects of infection before operation is therefore obviously of great

importance from the standpoint of functional improvement Attention must also be directed to purely mechanical factors

Reduction of Bronchial Secretions—The airways of the healthy segments should be kept as free of secretions as possible during the pre operative period The patient should arrive in the operating room with the lungs as dry as possible.

All patients who raise over thirty grams of sputum daily are placed in a head down position during sleeping and rest periods The foot of the bed is elevated to a distance of 12 to 18 inches Pillows are not permitted For lesions of the posterior basal segments the prone position is advised For lesions in the anterior portion of the lung the patient is advised to lie for the most part in the dorsal recumbent position In unilateral cases of bronchiectasis the patients may alternate between the prone position and the lateral position lying on the uninvolved side

The continuous positioning during the resting period is supplemented by three to five minute intervals of dependent drainage of an extreme degree carried out five times a day This is accomplished by instructing the patient to lean over the edge of the bed with the head as near the floor as possible Forced coughing is encouraged during this period

In certain cases where the sputum is particularly tenacious and copious, bronchoscopic aspiration repeated at stated intervals a few times may be very beneficial It has been our experience, however, that with well supervised postural drainage and inhalation of penicillin a satisfactory bronchial toilette can be provided for the great majority of cases Bronchoscopy should be avoided, if possible, during an interval of two to three days prior to resection Instrumentation may cause some mucosal irritation or injury, which decreases the tolerance of the mucosa for the indwelling intratracheal tube necessary at the time of resection

An associated upper respiratory or oral condition may demand attention before resection Sinus disease frequently complicates the picture in bronchiectasis Carious teeth and gum infections very often need care in patients coming to

resection for chronic abscess In most instances these associated conditions can be managed conservatively until the patient is in the convalescent period after resection The diseased lung undermines the health of the host to a greater degree than the other conditions and should have priority. Furthermore, in many cases definitive treatment of the lung with the adjunct use of antibiotics clears up the entire condition so that a radical attack on the sinus may not be necessary However, it has been our experience that if a radical antrum operation and a segmental pulmonary resection are both necessary, it is just as safe or possibly safer to treat the lung first Relief of symptoms and improvement in general health is more accelerated than with the reverse sequence The operation upon the sinus can be performed during the convalescent period without prolonging the hospital stay for a period longer than that required by the lung resection itself

Pre-operative Pneumothorax—One other step may be taken in an attempt to improve respiratory function before operation in addition to those measures which reduce secretions and thereby clear airways This applies to older patients who require a total resection of the lung and particularly to those with questionable respiratory reserve It has been our clinical observation that a preliminary period of gradual deflation of the affected lung before its total removal has advantages

1 It has value as a functional test if a portion of the lung which is to be removed carries part of the respiratory burden Advance knowledge of the ability of the contralateral lung to carry on is important

2 It allows a gradual collapse of the lung The cardiovascular system can then adjust itself more easily to the post-resection state

3 Symptoms are influenced favorably Cough is reduced, often considerably Secretions diminish Uncomfortable sensations of constriction or pain due to forces contracting the lung, particularly in cancer cases, are often relieved com-

pletely All of these gains are important because sleep, appetite, and strength are improved

4. The presence of air in the pleural cavity prior to exploration under local anesthesia allays disturbing reflexes which may take place with the first incision of the pleura Without previous air injection in patients with a free pleura, several minutes may be required for respiratory movements to quiet down Often coughing spells develop which are troublesome There seems to be a greater mediastinal swing and more often higher intrapulmonic pressures are required than in cases where previous air injection has been given

Preliminary pneumothorax is not attempted in bronchiectasis cases or in other lesions where suppurative processes are present The inflammatory process in these patients has usually produced adhesions and stiffened the mediastinal structures so that pneumothorax is either impossible or less helpful

The greatest field of usefulness is in older patients with cancer who have a low respiratory reserve It is of particular value where the disease prevents gas interchange yet has not blocked the pulmonary circuit to the corresponding segments In this event, a shunt is produced that is similar to a large arteriovenous fistula Varying amounts of blood go through the pulmonary circuit without benefit of oxygenation These patients may have dyspnea and show some cyanosis yet may be suitable risks for resection The preliminary collapse of such abnormal pulmonary shunts improves the cardio respiratory mechanism

Pre operative pneumothorax is induced gradually and maintained over a period of four to eight days On rare occasions, in borderline cases, it may be necessary to give a longer period of time for an adjustment Usually 300 to 500 cc of air can be given daily for three or four days, then the interval is lengthened and the refills varied according to the position of the lung as determined fluoroscopically The presence of adhesions that interfere with the progress of the treatment are contraindications to its continuance.

Chapter II

Operative Preliminaries

PRE-OPERATIVE MEDICATION

THE AVERAGE PATIENT is given three grains of nembutal (0 2 grams) two hours before operation, morphine, grains 1/6 (0 01 grams), and scopolamine, grains 1/150 (004 grams), one hour pre-operatively. Very nervous or robust persons are sedated more heavily. For children the same medication is used, but the dose, of course, is in proportion to their age and weight

VENOCLYSIS

A positive control over intravenous medication immediately before, during, and after operation is important Under local anesthesia the long saphenous vein, just above the ankle on one side, is dissected and a cannula of appropriate size is introduced into the vein Normal saline is used as a slow drip until the incision is begun This is replaced by citrated blood as soon as the incision is made The flow is regulated to replace the estimated loss of blood cubic centimeter for cubic centimeter as it takes place The amount of blood given varies with the estimated blood loss The average patient receives 1,000 to 1,500 cc during the course of the operation

In serious risk cases or where dissection is obviously going to be difficult, it may be wise to cut down on two veins and have a double venoclysis running If an actual double cutdown is not done, a second venoclysis set should be ready for immediate use On rare occasions the sudden loss of considerable amounts of blood demands rapid replacement

LARYNGEAL AND TRACHEAL ANESTHETIZATION

Preparation for intratracheal intubation is made by topical administration in a manner similar to that used in bronchoscopy Cocaine, in a 10 per cent solution, is used as a spray and for direct application with cotton swabs The anesthetization of the pharynx and larynx can be accomplished for the most part with an atomizer Following this, 3 cc of 2 per cent cocaine solution is slowly dropped in the larynx under mirror vision and is permitted to trickle down each side of the trachea

The next two steps in the preparation—skin washing and local block—are carried out before the actual insertion of the intratracheal tube This interval provides sufficient time for a better diffusion of the anesthetic agent and thus facilitates the intubation

FINAL WASHING OF THE SKIN

The skin of the chest is thoroughly scrubbed with green soap and water for about ten minutes At the conclusion of the scrubbing the soap is carefully washed away with large quantities of body temperature sterile water Following the skin washing, ether and then alcohol are used to remove the soap and greasy substances It is important that the skin be completely devoid of soap since the antiseptic agents used later in preparing the field may be neutralized and rendered less bactericidal

ANESTHESIA

Objection to General Anesthesia—The conventional method of administering anesthesia and for controlling pressures during resection of the lung employs a closed system with an intratracheal tube Many anesthetic agents have been used such as cyclopropane, ether, nitrous oxide, and ethylene It has been necessary for the anesthetist to carry a fairly deep plane of anesthesia in order to abolish the cough reflex which

is overstimulated by the indwelling intratracheal tube. The maintenance of a patent airway and the removal of secretions have presented the anesthetist with a difficult task. Repeated intratracheal aspirations throw the patient into bronchospasm, and control over the anesthesia is momentarily lost Degrees of anoxia result, and occasionally disturbing vagovagal reflexes follow Prolonged general anesthesia over two, three, or four hours may lead to tissue anoxia and favor shock Deep anesthesia relaxes bronchial musculature and favors the intrabronchial flow of secretions The state of semi-consciousness with depressed cough reflex following prolonged periods of general anesthesia favors stagnation of secretions in the bronchial system

Not being entirely satisfied with general anesthesia, we adopted a method of paravertebral block anesthesia and local infiltration followed by intratracheal intubation. This method has these advantages.

1 A better control of intratracheal secretions can be obtained
   - a Retained secretions in the abnormal lung are not released by bronchial relaxation
   - b The plane of anesthesia is not disturbed nor are periods of anoxia induced by aspiration via the intratracheal tube
   - c The cough reflex is present throughout the operation and is effective at the conclusion of the operation.

2 The anesthetic agent is less toxic This is an important consideration in long operations.

3 The immediate postoperative condition of the patient is better and nursing care is simplified Nausea and vomiting rarely occur. The oral intake of fluid and nourishment can be started without delay.

Anatomical Considerations in Blocking Intercostal Nerves—After each thoracic nerve emerges from the intervertebral foramen, it gives off a meningeal ramus, and the trunk then divides into two primary branches—the anterior and the posterior, the anterior branch being the larger of

the two (see Figure 2) The posterior branch takes a backward course and supplies the muscle and skin of the back The anterior branch, after giving off the ramus communicans to the sympathetic system, enters the intercostal space between the external and internal intercostal muscles The intercostal nerve encircles the hemithorax lying close to the lower margin of the upper rib in each intercostal space and is accompanied by the vein and artery Near the mid axillary line, the anterior branch of the intercostal nerve gives off a lateral cutaneous branch that in turn divides into anterior and posterior branches which supply the skin of that region The terminal branch, called the anterior cutaneous nerve, emerges in the parasternal line

Practical Details—After emerging from the intervertebral foramen, the thoracic nerve lies halfway between the transverse processes of the adjacent vertebrae and enters the subcostal groove at the level of the angle of the rib At this level, the intercostal nerve lies between the external intercostal muscle and the posterior intercostal aponeurosis, which structure replaces the internal intercostal muscle between the tubercle of the rib and its posterior angle In order to block a nerve, therefore, the anesthetic solution should be deposited between the external intercostal muscle and the internal intercostal aponeurosis

Landmarks—The spinous processes and the angle of the ribs are the superficial landmarks The ribs and the transverse processes are deep landmarks and serve as a guide for the needle

The tips of the spinous processes of the dorsal vertebrae do not coincide in position with their homologous intercostal spaces Therefore, while injecting laterally from the midline of the back opposite a spinous process, the operator does not reach the nerve corresponding to that spinous process The spinous processes, especially from the fourth to the ninth, slope downward and point to a rib or an interspace below The spinous processes can usually be easily felt by palpation, but it is not always possible to count them with accuracy The

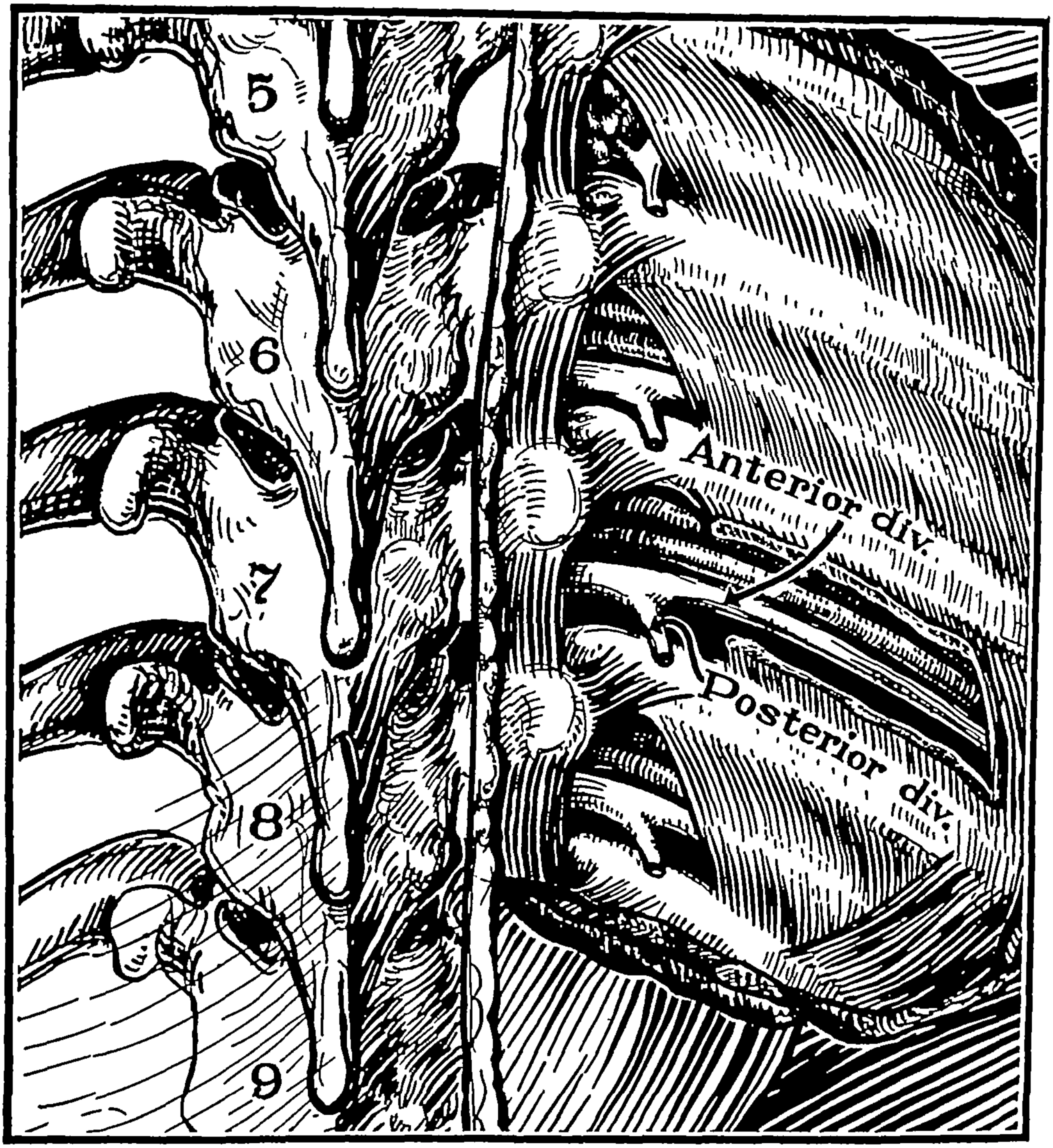
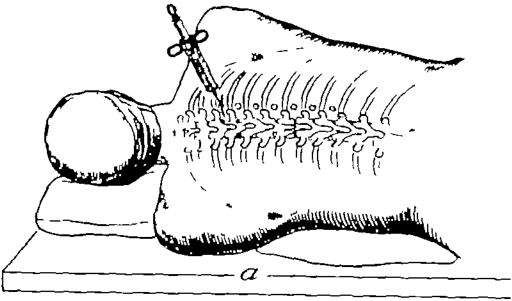


FIG 2 Drawing of paravertebral block anesthesia illustrating the anatomy of the thoracic nerves with their anterior and posterior divisions The external intercostal muscle has been removed from the intercostal space to expose more of the intercostal nerve The anesthetic solution is injected around the nerve at the level where the posterior division comes off

D12 spinous process is generally prominent and oval in shape The C7 is also prominent.

Solution—Procaine hydrochloride, 0 4 per cent, is used in the amount of 400 to 500 cc. Two minims of adrenalin 1.1000 are added for each 100 cc of the procaine hydrochloride solution.

Technique—For the purpose of injection, a paravertebral *line is selected 3 centimeters* from the spinous processes, and cutaneous wheals are placed about 1 centimeter above the tip of the spinous process (see Figure 3, a) Routinely, two nerves above and below the ribs to be resected are injected For example, in cases of pneumonectomy where the full length of the sixth and short posterior segments of the fifth and seventh ribs are resected, the nerves D3 to D9 are blocked This is done because the posterior branches widely overlap The needle is introduced, pointing slightly downward, inward, and forward toward the spine In this way there is little risk of puncturing the pleura or the lung The *needle will enter either the intercostal space directly or will*

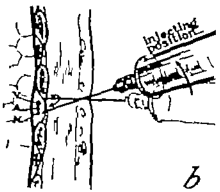


a

FIG. 3 Drawings of paravertebral block anesthesia illustrating the correct position of the needle for injection of the nerve

a. Cutaneous wheals at the sites of injection

b A sagittal section of the intercostal region close to the midline with the correct position for the original insertion of the needle indicated by dotted lines.



b

impinge upon the upper or lower margin of the upper rib. The needle is then shifted downward and advanced to a depth of 0.5 of a centimeter to 1 centimeter, varying the distance according to the individual patient (see Figure 3, b). If the needle happens to hit the nerve itself, injection is made without moving the needle Into each intercostal space 10 to 15 cc of the procaine-adrenalin solution is injected This amount will suffice to infiltrate the intercostal space between the muscles and anesthetize the anterior and posterior divisions of the thoracic nerve After that, the posterolateral line of incision and the underlying muscles are infiltrated Due to overlapping nerves from the opposite side, anteriorly, the paravertebral injection does not anesthetize to the midline This area should also be infiltrated subcutaneously The subcapsular space is next injected with approximately 30 cc of the solution.

INTRATRACHEAL INTUBATION

After the completion of the paravertebral block and local infiltration, the patient is turned on his back With the use of a laryngoscope, an intratracheal tube of appropriate size with an inflatable cuff is introduced Care is taken not to insert the tube beyond the carinal level The patient's mouth is packed with gauze and the tube is secured in place with adhesive tape The inflatable cuff is not inflated until positive pressure is required Irritation caused by the intratracheal tube is thus minimized

PRONE POSITION

Until three years ago the patient was placed in a lateral position for pulmonary resection The conventional side position and posterior approach was favored over an anterior approach because of a greater width of thoracic cage spread and the shorter distance to the hilum However, the side position had four distinct disadvantages

1. The diseased side was placed directly over the sound side Gravity drainage of secretion and debris from

the bad to the good lung was favored (see Figure 4, a)

2 Excursions of the thoracic cage on the sound side were impaired by the weight of the body

3 Mediastinal sag diminished the volume of the sound lung

4 The imbalance between thoracic cage excursion and diaphragmatic movement of the dependent side seemed to increase the aspiratory power and at the same time diminish the expelling force.

Our current practice is to reverse the relative position of the two lungs during the operative manipulation The patient is suspended face down with the chest turned so that the sound lung is uppermost (see Figure 4, b)

Advantages of the Prone Position—This new reverse position has proved to be of great help from several points of view

1 It is the most favorable of all for the natural drainage of bronchial secretions Material that does not spontaneously flow out or is not expelled by coughing can be more easily reached by aspiration Flooding of the contralateral lung is far less likely

2 The attainable range of thoracic cage and diaphragmatic excursion is greater than is possible in the side position

3 The amplitude of mediastinal swing or displacement is less

4 The use of intrabronchial positive pressure is not obligatory and is used only to test the bronchus or demark segments

5 Exposure of the posterior aspect of the hilum is facilitated The early and preliminary ligation of the bronchus in cases of pneumonectomy can be accomplished with minimal dissection and lung manipulation This is most important when the lung is densely adherent.

6 The weight of the lung itself allows it to fall forward, eliminating the necessity of lung clamps and the use of

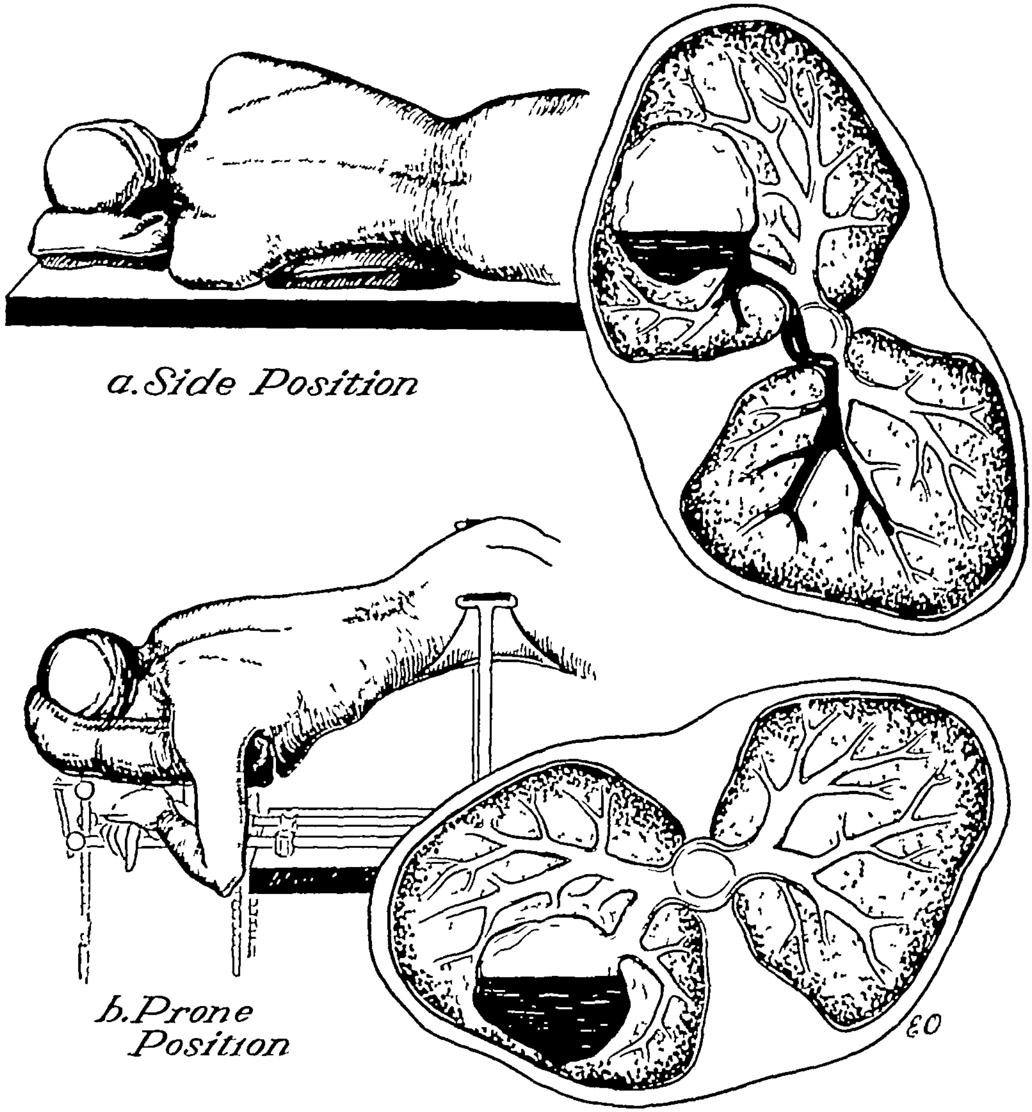


FIG 4 Drawings illustrating cross section of lung and the patient in the lateral and prone or face-down position The relationship of a fluid-containing lung cavity, the bronchial system, and the healthy lung is shown. Note the influence of gravity drainage in spill-over to the good lung. The routine position (a) used for thoracic cases and the new position recommended (b) are shown In the prone position the patient is supported and tilted so that the diseased lung is lower than the healthy lung during the operation

traction during dissection For most cases, the complete hilar dissection can be done by working entirely from the posterior aspect

7 Cardiac irregularities, bradycardia, or cardiac standstill have been practically eliminated as complications.

This may be due to avoidance of hilar traction during dissection

8 In the event of hemorrhage from the hilar area, the blood flows away from its source, thus permitting its control with greater ease In the side position the hilum is at the base of the cavity and quickly becomes sub merged in a pool of blood

Support for Prone Position—A special support* which can be adapted to any standard operating table has been

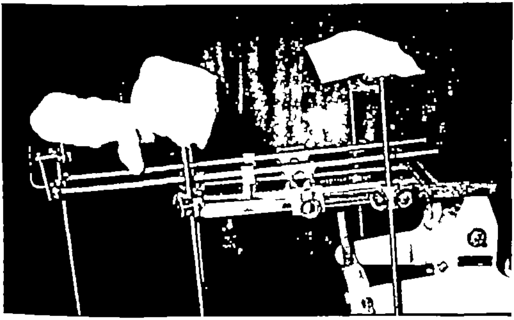


FIG 5 Photograph of the operating table with the special apparatus for supporting the patient in the prone or face-down position. Pelvic, shoulder and head supports are all adjustable. The apparatus may be quickly assembled and attached to any standard operating table. (This attachment was con structed for us by P Tuzik and Sons, 82 Chickatawbut St. Dorchester Mass.)

devised (see Figure 5) The support consists of three parts 1) head rest, 2) shoulder braces, and 3) saddle for pelvic girdle. The head rest is horseshoe shaped and cushioned with rubber It allows exposure of the face The mechanism of the head rest can be adjusted to any position or angle The cushioned shoulder braces are arranged so that they can

* Constructed by P Tuzik and Sons, Dorchester Mass.

be raised or lowered and moved from side to side independently The pelvic girdle support is a heavy canvas saddle which is attached to the operating table It is movable and can be raised to any desired level After the patient has been placed on the support, the shoulder and pelvic saddle on the affected side are lowered about 20 degrees In this way, the affected side becomes the more dependent side Furthermore, the operating table top can be tilted laterally to increase the dependency of the affected side The head end

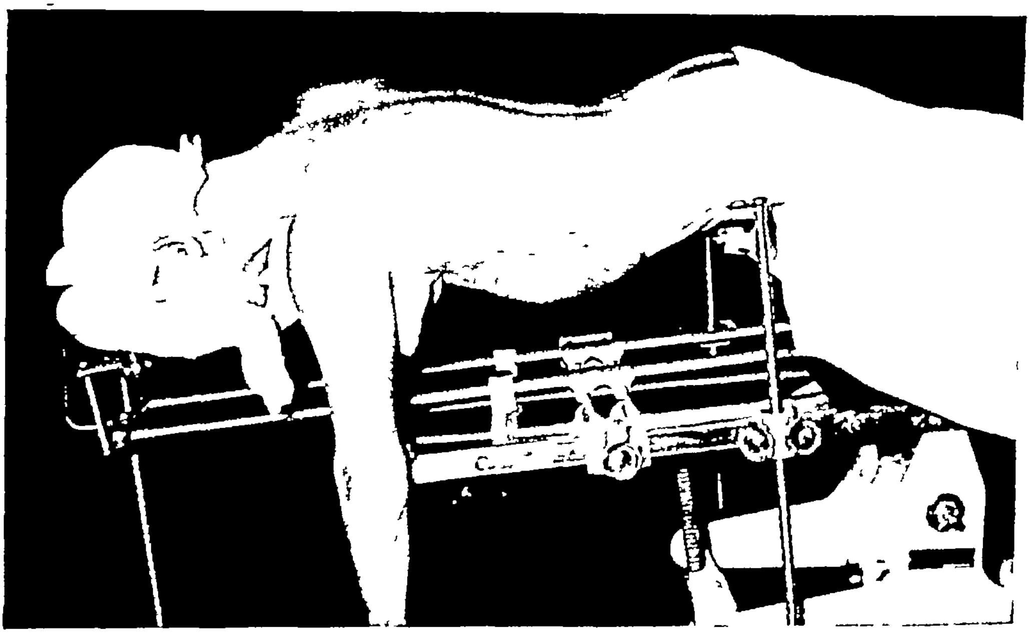


FIG 6 Photograph of the patient on the operating table lying in face-down position on supporting apparatus Note that the patient's head is lower than his hips The left side is the diseased side and is more dependent than the healthy side.

of the table may be adjusted to obtain any desired inclination of the head and chest The lower two-thirds of the chest and upper abdomen are free of supports and clear the top surface of the operating table sufficiently to permit access to the anterior midthorax (see Figure 6)

A thoracic table (experimental model)* has been constructed with shoulder and head supports incorporated with a half-length table top This permits placement of the patient

* Developed by the American Sterilizer Company, Erie, Pennsylvania

lower extremities is movable fore and aft in the horizontal plane This permits an adjustment for varying shoulder-pelvic lengths of different patients

4 The table top is adjustable in the vertical plane independently of the shoulder and head supports

5 The entire superstructure of the table may be elevated as a single unit by means of a hydraulic pump similar to that of a standard operating table.

6 The table top and supports may be tilted up to 20 degrees in either direction (40 degrees total) A body brace at the side of the hip stabilizes the patient in the lateral tilt position.

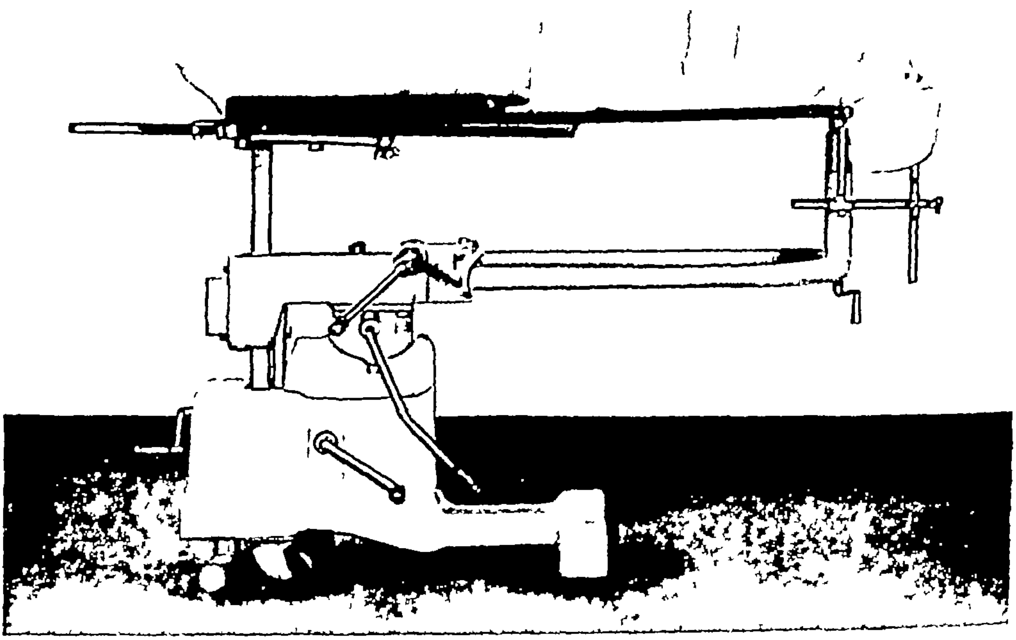


FIG 7 Overholt-Comper Thoracic Table

b Table with x-ray-penetrable table top in place and patient in bronchoscopic position The clearance below patient provides space for x-ray unit Film exposure and fluoroscopic examination may be made with patient on table in either position (This table was constructed by the American Sterilizer Company, Erie, Pennsylvania)

7 The table top and supports may be inclined, to place the patient in the Trendelenburg position

8 Conversion to a full length table is possible by inserting, as an attachment, the upper half of the table top This is constructed of x ray penetrable material which permits fluoroscopic and radiographic examination Bronchoscopic operations may conveniently be carried out under the fluoroscope (see Figure 7, b)

CLOSED CIRCUIT, OXYGEN AND NITROUS OXIDE, ETHER, OR CYCLOPROPANE

An anesthesia apparatus is made available for the administration of oxygen through the intratracheal tube when positive pressure is required

For some cases, we have found it helpful to supplement the paravertebral block and local anesthesia with the analgesic effect of nitrous oxide or ether A mixture of oxygen and a low concentration of nitrous oxide or ether is given if patients become restless or indicate that they are having pain In most cases it is possible to explore and place the preliminary bronchial ligature without any supplementary anesthesia Upon rare occasions, cyclopropane has been added to the breathing mixture to produce a more rapid analgesic effect than can be accomplished with nitrous oxide.

SKIN ANTISEPTIC

Zephiran chloride (alkyl dimethyl benzyl ammonium chloride) 1 1000 solution is used as a skin antiseptic This solution is liberally applied at the time of the procaine injection and again prior to final draping with towels

ULTRAVIOLET IRRADIATION OF OPERATING ROOM

Two ultraviolet units* are permanent fixtures in the operating room Each fixture incorporates one 12 inch cold

* Hanovia Chemical and Manufacturing Company Newark, New Jersey

cathode type tube of pure transparent fused quartz A filter-jacket is provided which limits ozone production Each unit is an intense source of ultraviolet radiation with 95 per cent of the radiation between 2500 and 2600 angstrom units Two units will instantaneously and continuously sterilize 10,000 cubic feet of air, if sufficient ventilation is provided. Air movement is necessary to bring all air in contact with the rays Stagnant air also permits an over-concentration of ozone Dust particles in the air resist complete sterilization and their exposure time is usually shortened due to increased velocity The units are placed in the angle between the wall and ceiling, one on either side of the operating table The entire room is used as a chamber for air sterilization as the rays reach practically all areas. Air currents constantly shift the air position so that the bactericidal effect of the rays is continuously brought into play. The operating room personnel wear a clerk's eye shade or plain glasses Either gives ample protection to the eyes. This simple yet necessary precaution has not proved to be inconvenient.

Chapter III

General Considerations Pertaining to All Resections

THE OPENING

IT IS A FACT that the prone position obligates the use of a posterolateral approach It could also be said that the prone position was developed because of a preference for a posterolateral approach Aside from its necessity, because of the position into which the patient is placed, there are other preferential reasons for this approach over an anterior one If occasion demands, a wider rib spread can be obtained The approach to the posterior root of the lung is shorter and can be reached with less manipulation of the lung The posterolateral approach affords a better general view of all intrathoracic structures This is particularly true when the *lung mass itself fills or nearly fills the hemithorax after* the chest is open and pleural attachments have been separated Finally, the dissection of hilar structures can be carried out with more freedom with this avenue of approach

The Skin and the Muscles—The incision is made posterolaterally It begins at the level of the fourth rib between the scapula and the spine, is continued downward and forward two inches below the tip of the scapula, and is extended to the anterior axillary or, at times, to the midclavicular line A long incision of the skin and soft tissues is a prerequisite for proper exposure and convenient access to the thoracic cavity The incision should be long enough to allow full spreading of the ribs without the skin being under tension Plenty of room facilitates a thorough exploration and mastery of any unexpected difficulty that may arise during the course of the operation The handling of pulmonary tissue

and hilar structures is made easier if the rib spread is six or seven inches, permitting the unimpaired work of the fingers of both the surgeon's hands within the wound. The wider the exposure the less retraction of the lung is required. Undue forcible traction or much handling of the lung produces vago-vagal reflexes, slow heart action, depression of blood pressure, and often troublesome cough reflexes

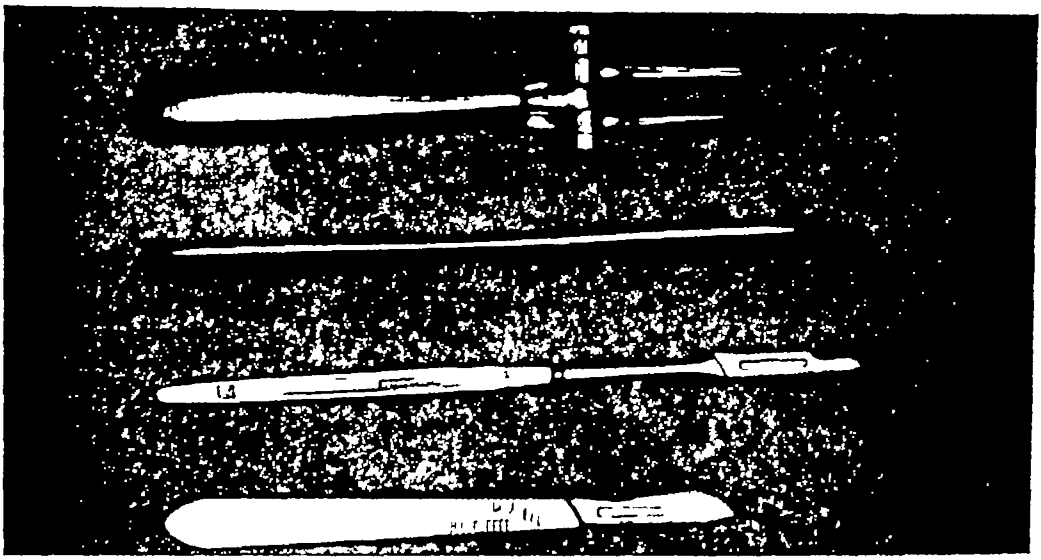


FIG 8 Instruments used in pulmonary resection
a An adjustable double-bladed knife, used for the excision of the cutaneous scar in performing a post-resection thoracoplasty. Two long handle knives, used for sectioning the bronchus (one with a blade angled to 45 degrees) A standard Bard-Parker general utility knife The angle blade is manufactured by Rudolph Beaver, 478 Trapelo Road, Waltham, Massachusetts.

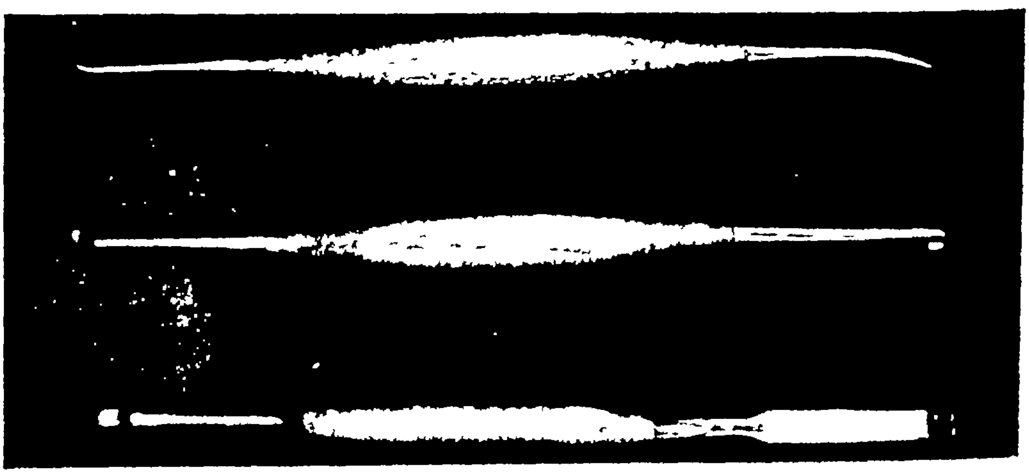


FIG 8 Instruments used in pulmonary resection.
b. A matched set of periosteal elevators (Overholt)

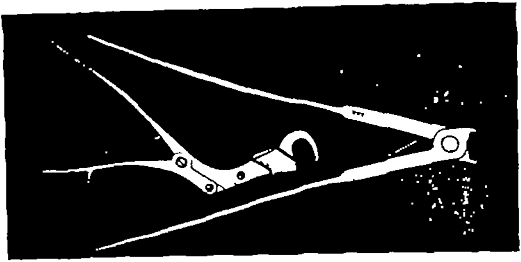


FIG. 8 Instruments used in pulmonary resection.

c. Costotomes. The larger one is an inexpensive tack cutter used by shoe makers.

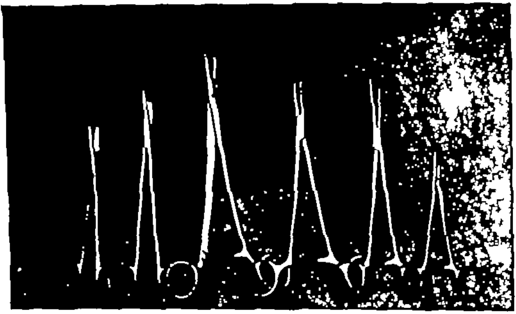


FIG. 8 Instruments used in pulmonary resection.

d Two dissecting scissors (Metzenbaum), curved forceps for holding gauze pledgets for blunt dissection (Overholt) right angle hemostatic and dissecting forceps (Lower) holding forceps (Allis intestinal) and mosquito hemostatic forceps (Halstead)

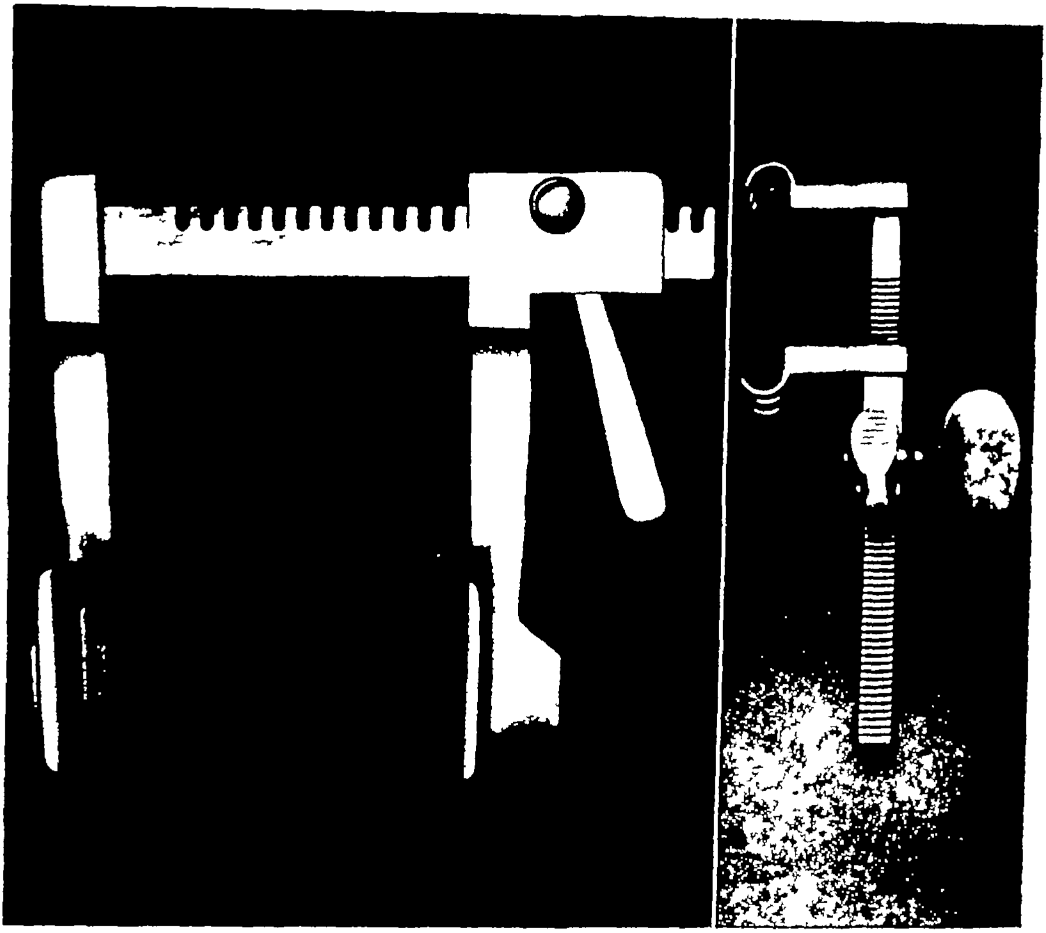


FIG 8 Instruments used in pulmonary resection

e Rib retractor (Finochietto)
f Rib approximator (Bailey)

The skin edges are protected with towels which are temporarily sutured to the superficial fascia since the wound edges may be exposed for considerable periods of time Towel clips are too traumatizing and less certain of holding the towels in position than sutures The added time necessary to suture protective towels in place is justified by more favorable wound healing

The muscles of the back are divided in a line corresponding to the skin opening By sharp dissection, the space between the inferior border of the trapezius and the superior border of the latissimus dorsi is entered There is usually a vessel here which requires ligation Once the plane of the peri-thoracic fascia has been reached, the forefingers of the

surgeon and the assistant are introduced beneath the rhomboideus major and minor The fingers are applied snugly against the muscles to stop any bleeding that may occur while the muscles are being divided (see Figure 9, a) When the muscles have been divided, the fingers are slowly released

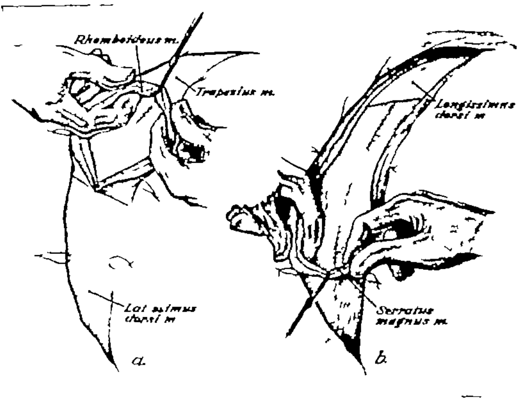


FIG. 9. Drawings illustrating division of the muscles of the chest wall

a. The trapezius and the rhomboideus muscles are being divided with finger control of the bleeding points. Note loops of thread (two pair) placed diametrically opposite each other before incision is made to facilitate accurate realignment in closure.

b Division of the latissimus dorsi and serratus magnus muscles is being carried out

and, as the bleeding points are demonstrated, they are individually secured The latissimus dorsi and the serratus are divided in the same fashion (see Figure 9, b) With the use of the long incision the scapula can be lifted up easily from the thoracic wall making the fifth and sixth ribs accessible along their entire lengths

The Ribs—For pneumonectomy cases it is important to make provision for an air-tight closure of the thoracic cage as control of intrapleural pressure postoperatively is essential The position of the mediastinum cannot be otherwise regulated. It is easier to close the chest in an air-tight manner if a full rib length has been resected The intercostal muscle

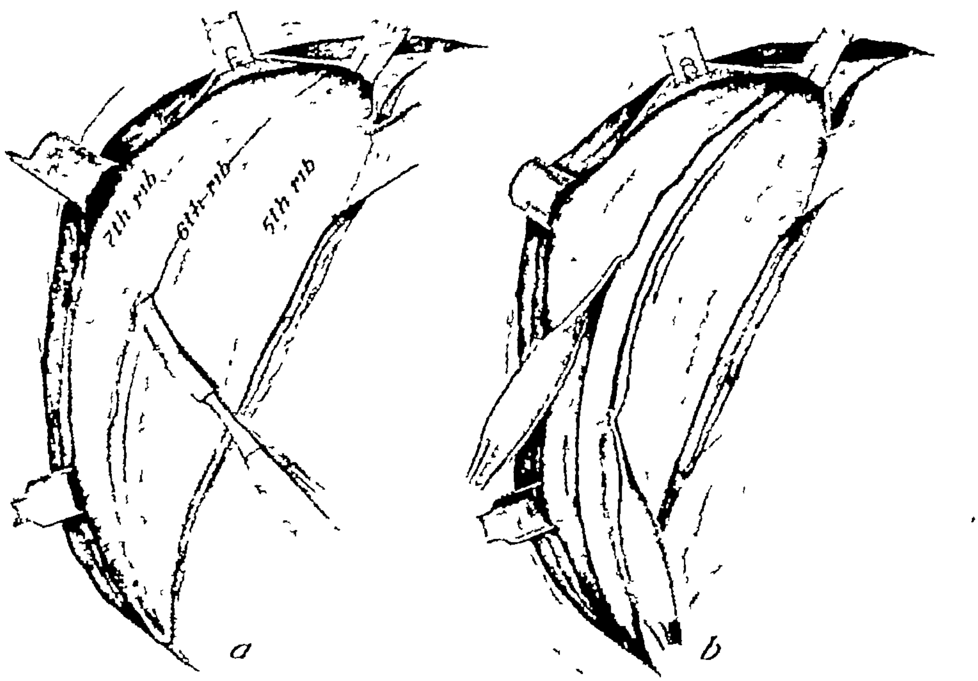


Fig 10 Drawings illustrating the subperiosteal resection of a rib

a The Overholt Surface Elevator is being used to denude the outer surface of the rib

b The Overholt Edge Elevator is shown being used in two positions to clean the upper and lower margins of the rib

and periosteum provide adequate soft tissue for suturing whereas the singly divided intercostal muscle of an interpace cannot be so satisfactorily sutured We almost routinely esect the full length of the sixth rib (see Figure 11, a) One-ialf to one inch paravertebral segments of the fifth and sev-nth ribs are also resected The intervening muscle bundles re divided, and the vessels are ligated (see Figure 11, b) The intercostal nerves are dissected and are divided. After

the full length of the sixth rib and short paravertebral sections of a rib above and below have been removed the thoracic cage will spread easily for a distance of six to eight inches The widest portion of the opening is directly over the hilar structures (see Figure 12)

After lobectomy or after segmental resection an air tight closure of the chest is not mandatory The escape of air from the pleural space does not influence necessarily the position of the mediastinum In fact an exit for air into the soft tissues of the chest wall favors re expansion of the remaining lobe

FIG. 11 Drawings illustrating method of opening thoracic cage and preparation for self retaining retractor

a. The full length of the sixth rib is being removed. Inch segments of rib above and below have been removed.

b The intercostal vessels are being ligated The fifth and sixth intercostal nerves have been severed The nerve has not been included in the ligature.

c. Finger pressure is being exerted on the lung surface to facilitate of adhesions with scissors The costal structures are being simultaneously retracted with rakes

d. Final exposure with Finocchietto retractor in place.

FIG. 12 Photograph of intrathoracic exposure after completion of right pneumonectomy Note width of rib spread The diaphragm has been depressed slightly with a band retractor The hilar area is well centered in relation to the opening The arrow points to the bronchial stump

The exposure of the thoracic cavity is obtained by removing two short paravertebral rib segments (see Figure 13, a) One intervening muscle bundle is cut The artery and the intercostal vein are ligated, and the nerve is cut but not included

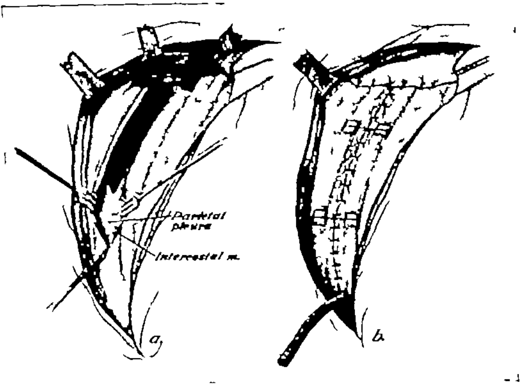


FIG. 13 Drawings illustrating the opening and closing of the thoracic cage for lobectomy and bronchopulmonary segmental resection

a. Two small paravertebral rib sections have been removed subperiosteally The intervening intercostal muscles and vessels have been ligated and cut The intercostal muscle and parietal pleura are being divided for the full length of the intercostal space

b Two subperiosteal pericostal ligatures have been placed. The intercostal muscle has been closed with interrupted sutures. The longissimus dorsi has been sutured to the intercostal muscles. A rubber tube has been placed in the anterior portion of the wound for temporary negative suction and drainage

in the ligature The intercostal tissues are incised for the full distance of the rib (see Figure 13, b) For lower lobectomy, the sixth and seventh ribs are usually divided and the pleural cavity is entered through the sixth intercostal space If the upper lobe is overdeveloped and the lower lobe totally collapsed or if one suspects dense diaphragmatic adhesions, the seventh interspace may be preferable For an upper lobectomy, small sections of the fifth and sixth ribs are removed, and the pleural cavity is entered through the fifth intercostal space Occasionally, in the past, in the performance of lobectomy, a long, intercostal incision was used with

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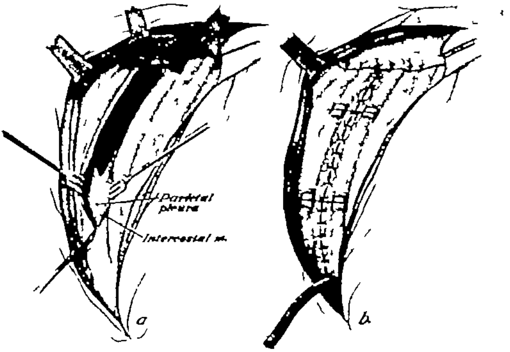

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out resecting any rib segments The lateral spread is not adequate for a traction-free and meticulous dissection of the lung root It was also discovered that in a high proportion of cases either the rib above, below, or both were fractured by the rib spreader. We now elect to deliberately divide the ribs above and below the intercostal line of incision.

Thoracic Cage Opening in Complicated Cases—In post-thoracoplasty cases requiring resection, the previous posterolateral scar is excised The incision is extended well around anteriorly, usually to the midclavicular and occasionally to the parasternal line Entering the pleural cavity may present difficulties because of the irregular and snarled arrangement of regenerated osseous tissue Access to the pleural cavity is obtained more easily if the surgeon pursues the route of the intercostal space from an anterior point, and then works posteriorly rather than if he tries to remove large segments of regenerated ribs at first After a cleavage plane has been developed intrapleurally or extrafascially from an anterior position, a spread of the costal cage there aids in the development of the posterior aspect of the thoracic cage Frequently, virgin rib stumps are found anteriorly In this event, entering the pleural space in the fifth interspace anteriorly can be carried out with great facility The paravertebral regenerated portions of three or more ribs are removed The rib edges are first spread apart with rake retractors and the intercostal space is developed by sharp dissection Paravertebrally, the regenerated ribs are cut as high and low as is necessary to provide wide access to all parts of the chest

In cases with draining chest sinuses, empyema, or cavernostomy openings, an effort is made to work in a clean field for the resection An elliptical incision is made about the chest wall defect or draining sinus The edges of the isolated ring are sutured over the opening, thus sealing off the infected area The sinus tract is dissected free all the way down to the visceral pleura The operative field is prepared again

with the skin antiseptic, is redraped with towels and the routine posterolateral incision is made The intrathoracic part of the operation is carried out within a clean field After the bronchovascular structures of the lung lobe, or segment have been divided, the final dissection of the lung in the sinus or empyema area is done The lung, sinus tract and inverted skin are then removed in one sealed mass

The Exposure—The pleura is incised in the bed of the resected rib in pneumonectomy cases or in the intercostal space in lobectomy cases The presence of extensive adhesions between the lung and chest wall at the incision site requires careful dissection It has been found that certain principles of pleural dissection and lung handling have been helpful

1 The separation of the lung from the chest wall is started in areas where the adhesions are thinnest Frequently this area will be found anteriorly
2 Pleural adhesions are divided by sharp dissection (see Figure 11, c) to avoid injury to lung parenchyma However, adhesions which are filmy, loose, elastic, and avascular often can be released by blunt dissection Adhesions containing vessels of consequence are divided between ligatures First it is helpful to find the soft areas of pleural symphysis to work between and around the difficult areas, and then, after encirclement of the dense adhesions, to complete their division Extensive firm and vascular adhesions may result in a long and tedious operation However, even in cases where the lungs are virtually frozen in the chest, the dissection usually can be accomplished cleanly and with little loss of blood
3 Whenever possible, pleural adhesions are divided in preference to stripping the endothoracic fascia The interpleural plane is less vascular In cancer cases, however, it may be desirable to follow the endothoracic fascia layer if the growth has invaded the visceral pleura In cases of tuberculosis, if the covering over a

cavity is thin, it is often wise to strip the endothoracic fascia in that area

4 The rib spreader is placed only after the lateral aspect of the lung has been liberated from the chest wall This avoids tearing of adhesions and stretching of the lung as the ribs are spread apart (see Figure 11, d) It is very important that the rib retractor be spread gradually Sudden tension on intercostal tissue and nerves may give rise to painful stimuli and throw the patient into breathing irregularities and even into temporary apnea

5 Lung clamps or forceps are avoided, for they traumatize the lung, increase the likelihood of contamination, and encourage assistants to make undue traction on the lung root

6 If infected areas within the lung substance are inadvertently opened, general soiling should be avoided if possible The incidence of postoperative empyema and contamination at the time of operation are closely related Quick aspiration of infected material, the use of gauze pads to wall off the area, and suturing of the rent are important steps that should be taken immediately After the area is sealed, thorough washing of the area with sterile saline reduces the number of bacteria which remain

7 Procaine hydrochloride, 5 to 10 cc of a 1 per cent solution, is injected into the vagus nerve and perihilar tissue early in the course of the dissection to block vago-vagal reflexes On the left side care should be taken to inject the vagus below the origin of the recurrent nerve. Manipulation of the lung or any undue traction upon the hilum may produce troublesome reflexes that impair cardio-respiratory function Irregularities in respiration, a fall in blood pressure, slowing of the heart, or even cardiac arrest may result The cocainization of the trachea and bronchi before the operation also tends to quiet these troublesome reflexes

THE DETERMINATION OF THE EXTENT OF THE RESECTION

Fortunately, the lungs lend themselves well to study by x ray, bronchogram, endoscopy, and differential functional tests The thoracic surgeon is therefore furnished with more precise information concerning the nature, location, and extent of the pathological process than is given the surgeons who explore for internal disease in other regions of the body However, the final decision as to the extent of the resection must be deferred in many instances until after additional data is obtained at surgical exploration

It is not within the scope of this book to include a discussion of clinical pathology of these conditions which require resection for their successful treatment However the plan of the extent of each individual operation is determined by the character and extent of the disease The exploration of the chest is in reality a diagnostic procedure The accuracy of the pre operative diagnosis is checked A clearer picture of the extent of the disease is obtained and operability is determined This final diagnostic examination also involves technical procedures and governs subsequent operative steps to be taken Therefore, it is appropriate to consider at this time some of the adjustments forced upon the surgeon by various situations encountered at exploration

With the chest open, changes in the pleura, the status of the fissures, the gross aspect of the lung, pericardium, and mediastinum should be appraised Removal of tissue and microscopic study after frozen section are often required

Reference will not be made to the type of resection required in the emergency treatment of traumatic lung lesions In civilian practice pulmonary resection is almost always an elective procedure However, during the last war in a few isolated instances a thoracic surgical team was able to remove a lung or lobe for wounds of the great pulmonary vessels and bronchi The plan of resection in war surgery may not be fully worked out prior to exploration The problem however, is more clear cut than in the handling of

diseased lungs, for the surgeon proceeds at once in checking hemorrhage and in the removal of devitalized tissue.

Primary Malignancy—When thoracic exploration is performed for primary carcinoma it is done either with the advance knowledge of the presence of the cancer (bronchoscopic biopsy or sputum examination) or because of strong presumptive evidence that cancer is present In the event of established cancer the unknown factors to be settled at exploration are first, to determine the presence or absence of an extrapulmonary extension of the tumor, and second, to decide whether or not it is technically possible to remove the entire lung as a curative or palliative objective In the event of suspected cancer the surgeon must first establish the diagnosis before proceeding with a plan for resection if verification is at all possible

Inspection and palpation of the lung often give the surgeon a fairly clear idea of whether he is dealing with cancer or with an inflammatory process As in malignancy of other soft parts there is usually a tendency for contraction and puckering of adjacent tissues There is also a characteristic firmness to the tissue and fixation of contiguous structures Small stem bronchus lesions may provide no parenchymal changes due to the presence of the tumor itself However, small lesions on which infection has not been superimposed may be palpated and directly located within the bronchial wall in the primary or secondary hilum with a considerable degree of accuracy. If tissue for frozen section can readily be removed from a mass on or within the lung without the danger of opening an infected area, this is done. Frequently, it is more expedient to examine hilar or mediastinal glands Positive findings of metastasis in a gland settles the diagnosis and permits the surgeon to proceed at once with a palliative resection if the tumor extension has not made hilar treatment technically impossible Experience has shown that much is to be gained from removal of a cancer-bearing lung even in the presence of mediastinal or chest wall extension So often in advanced disease secondary infection is present and precip-

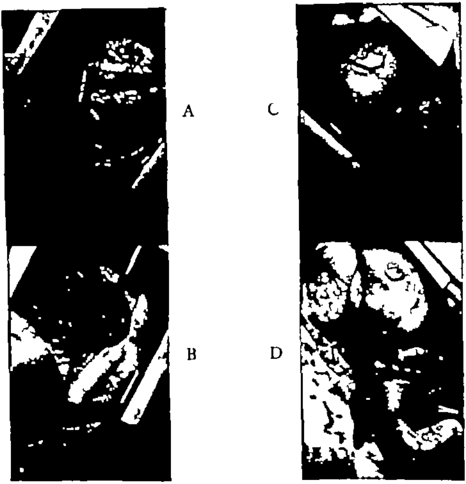


FIG 14. Photographs of various lesions encountered upon intrathoracic exploration.

a. A middle lobe which is indurated and airless as a result of suppurative *bronchiectasis. The lobe has been rotated and lifted up to better expose its* mediastinal surface making the horizontal fissure appear vertical The basal segments of the right lower lobe have just been removed The remaining enlarged superior segment almost completely fills the inferior and posterior portions of the chest

b The under surface of the superior segment of the lower lobe The basal segments have just been removed (Same patient as in a.) Note that the surface is relatively dry and that the segment remains expanded without air leak.

c. An atelectatic lingular segment of the left upper lobe There is a rudimentary fissure between the lingula and the anterior segment The basal segments have just been removed The remaining overdeveloped superior segment of the lower lobe is clearly shown

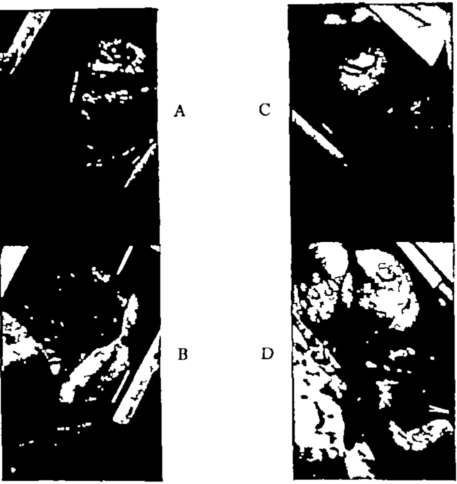
d A giant cyst of the left lower lobe and smaller cysts in the lingula. The demarcation between healthy lung tissue and the cyst is clearly evident

Benign Tumors—Exploration of the chest under a diagnosis of bronchial adenoma frequently forces upon the surgeon a difficult decision in regard to the extent of resection There are two major considerations, first, the precise localization of the base of the tumor, and second, the determination of the presence or absence of islands of tumor cells in adjacent or hilar glands For tumors well down a lobar bronchus the safe level of lobar bronchial amputation can be determined reasonably well before exploration Upper lobe lesions, with extension into the mucosa of a main stem bronchus definitely indicate pneumonectomy The exact level of bronchial wall involvement cannot always be determined bronchoscopically Adenomas have a tendency to protrude for some distance up the lumen of a bronchus obscuring its base so only the dome of the intrabronchial mass is seen. After exploration, in case of doubt the safe line for amputation may have to be determined by bronchotomy The wall of that lobar bronchus known to need resection is opened and the precise level of bronchial involvement is determined This procedure increases slightly the risk of empyema but this is justifiable if a lobe of the lung is thereby conserved

The second consideration is the status of the hilar and mediastinal glands as found at exploration The so-called benign adenomata do occasionally metastasize. If islands of tumor cells are found in mediastinal glands, then a complete resection with removal of all possible glands is indicated If the only involved gland is a lobar hilar gland and its complete removal can be accomplished with the lobe resection, then lobectomy may be performed

In the treatment of right lower lobe lesions it is wise to consider amputation through the intermediate bronchus. This increases the margin of safety, for an extra 1 5 centimeters of bronchial wall may be removed with very small additional sacrifice of functionable lung tissue

Intrapulmonary benign tumors other than adenoma are rare Hamartoma, fibroma, and lipoma have all been found beneath the pleura or not far down within the lung substance. They are well localized, usually round, and with no evidence



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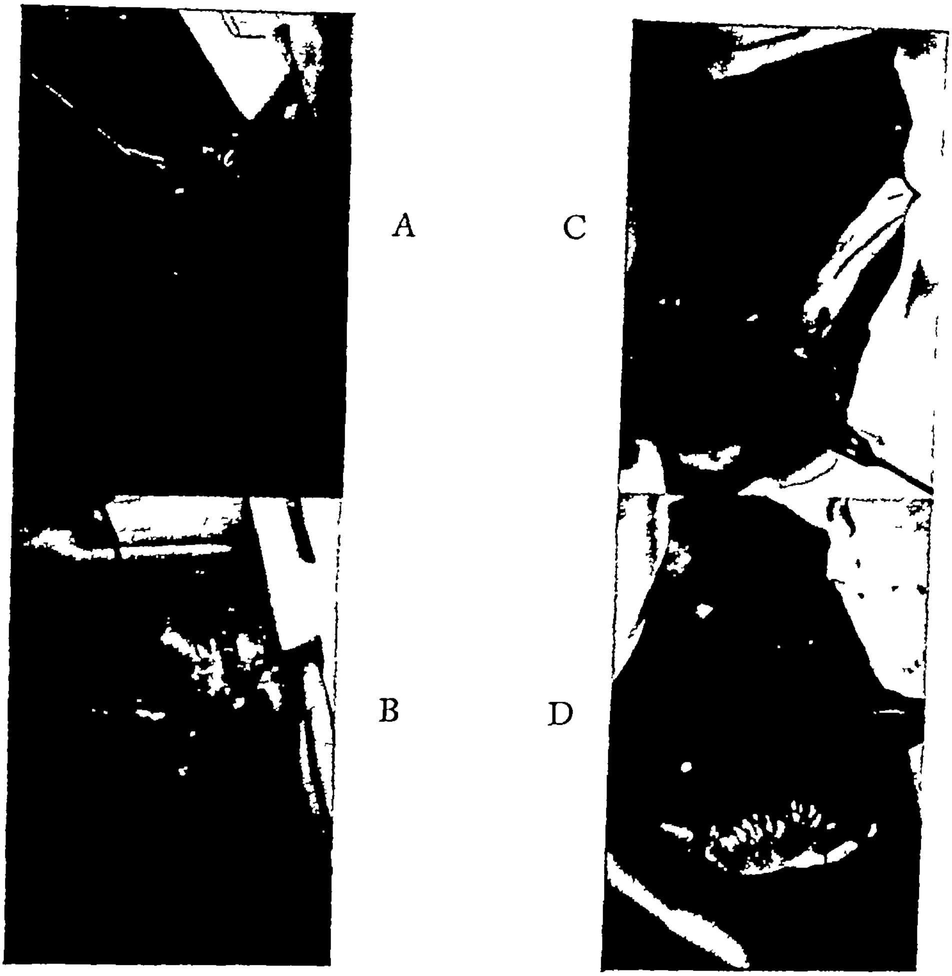


FIG 15 Photographs of various lesions encountered upon intrathoracic exploration

a A peripheral bronchogenic cancer in the left upper lobe The tumor is being palpated between the surgeon's thumb and forefinger It was situated near the surface of the lobe Tissue for frozen section was easily obtained prior to resection

b Exposure of a left lung which contained a carcinoma in the left upper lobe This lobe is small, contracted, and indurated Its surface shows puckering, and nodules of tumor appear on the lingular segment The lower lobe is normal to gross inspection The interlobar fissure is not well developed

c Exposure of a tuberculous lung and empyema cavity Both the visceral and parietal pleura are markedly thickened The visceral pleura has been opened exposing a portion of the lung at the level of the great fissure

d A large pedunculated fibroma which is attached to the left lower lobe The tumor has been lifted out of the chest and is connected to the lower lobe by a broad vascular pedicle The patient was in the conventional side position at operation

of invasion The pleura is not puckered, and adjacent lung tissue slides over the tumor surface The tumor is almost always near some surface and accessible for biopsy Benign tumors naturally should be treated by the most conservative type of resection that ensures their complete extirpation Local removal, segmental resection, or at the most lobectomy will be sufficient for the great majority

Suppurative Disease—Chronic non specific inflammatory processes may present all the clinical and gross features of a neoplastic lesion The lesion may appear indurated, irregular, and invasive The hilum may be filled with enlarged lymph nodes A representative frozen section of various glands will be negative for malignancy A hasty decision and diagnosis of cancer in such a situation may lead to the sacrifice of functional tissue if pneumonectomy is performed The surgeon is not entitled to label a doubtful condition as carcinoma and proceed with a radical extirpation until histological verification has been made if it is at all possible to obtain tissue A biopsy may be done in solid areas of parenchyma The pathologist's report may be misleading, since very often small endobronchial tumors will lead to inflammatory changes in the periphery of the bronchopulmonary segment. Often peribronchial tissue at a suspicious area of bronchial thickening may be obtained In the event that a definite differential diagnosis between a unisegmental or unilobar inflammatory lesion and carcinoma cannot be made, the involved segment or lobe should first be removed and the surgical specimen given to the pathologist for careful study If then carcinoma is found, pneumonectomy may be completed For extensive lesions involving all lobes, this recommended plan of treatment obviously does not apply

Bronchiectasis—In bronchiectasis, careful bronchographic studies will usually serve as an accurate guide as to the extent of involvement in the various bronchopulmonary segments The surgeon is able therefore to plan in advance the number of segments that should be resected A careful inspection and palpation of the lung tissue will furnish im

portant data as to the gross anatomical changes in both the affected and uninvolved segments The involved segments may be contracted and airless or they may be emphysematous and oversized with scant pigmentation The healthy segments, because of their vicarious function and compensation for volume loss, may be enlarged When the chest is opened, it is interesting to watch the effect of open pneumothorax upon the lung Emphysematous diseased segments fail to deflate as rapidly as the normal segments. Also, normal segments expand more rapidly than the diseased segments as the intrabronchial pressure is raised

The state of the fissures between the lobes, and the surface markings of the lung suggesting rudimentary fissures between the bronchopulmonary segments deserve special consideration since we are dealing with a pathological condition that only affects certain portions of the lung and should be treated accordingly

Truly complete fissures are a rare finding The minor fissure between the upper and middle lobes is incomplete in most cases The great fissure is frequently undeveloped at its upper portion Normally developed fissures frequently become fused as a result of disease However, undeveloped and fused fissures can always be separated by retrograde dissection. No lung tissue should be sacrificed because of the absence or incompleteness of the fissures

Rudimentary fissures or notches indicate peripheral boundaries of segments or subsegments One is frequently found dividing the upper and lower (lingular) divisions of the left upper lobe Less often is a rudimentary fissure found between the superior and basal segments of the lower lobes

The most important exploratory finding in bronchiectasis is not determined visually however. Palpation of the various segments for areas of induration and thickening is often more reliable than the bronchogram This particularly applies to subsegments of the lingula, the right middle lobe, and to subsegments of the anterior division of the upper lobe Normal lung tissue when palpated between thumb and forefinger has a characteristic softness and delicate crepitation with some

variations due to age Minimal areas of disease may be readily determined by palpation Indurated borders or fringes of the segment may be the only evidence of involvement. These areas cannot be palpated with accuracy unless all adhesions are divided and the lung tissue is liberated from chest wall, diaphragm, and pericardial fat pads Areas of induration, spotty nodulation, and thickened bronchi are indicative of chronic pneumonitis and bronchiectasis Segments so involved should be resected regardless of the bronchographic interpretation Earlier in our experience various changes of this kind in the lingula were not used as a basis for resection if the bronchi were clearly within normal limits as to width in the bronchograms Later it was demonstrated by re examination with lipiodol that the bronchi of the lingula were involved and should have been removed

Tuberculosis*—The plan of resection in tuberculosis may be very obvious and clear cut prior to exploration Serial x rays over a long observation period and bronchoscopic findings usually make an accurate appraisal possible For example total lung involvement or main stem bronchial disease will require the surgeon to proceed at once with a total resection if excisional therapy is to be undertaken A total resection is also obviously required for cases in which an extensive and complete thoracoplasty has been previously performed In planning a resection for right basal tuberculosis with endobronchial involvement it is wise to deliberately plan to sacrifice the middle lobe and amputate through the intermediate bronchus This permits the highest bronchial closure short of complete removal

In certain cases the localization of disease with respect to segments and lobes is not possible prior to exploration X ray studies may be misleading and if so the process is found to be more extensive than anticipated Marked contraction of an

* The authors, with Norman J Wilson and John T Szypulski have discussed at length the considerations that should be given to planning the extent of resection of the tuberculous lung in "Pulmonary Resection in the Treatment of Tuberculosis," *J Thoracic Surg* 15 384 417 1946, and in "Pulmonary Resection in the Treatment of Pulmonary Tuberculosis" *American Review of Tuberculosis* 55 198 222 1947

upper lobe with displacement of the lower, particularly its superior segment, may have occurred Careful palpation of the supposedly healthy segments should be carried out. Areas of induration or discrete nodules may be found in unsuspected segments A difficult decision is forced upon the surgeon. Unless the nodules found are calcified or of known stability, a more extensive resection than originally planned is usually the best. The superior segment of the lower lobe has occasionally been found to be involved when only upper lobe disease was previously suspected If the disease is confined to the superior segment of the lower lobe, this segment should be removed at the time of the upper lobectomy, in preference to pneumonectomy

The principle of conserving uninvolved lobes or segments should apply in tuberculosis as in other non-malignant diseases The presence of a fused or undeveloped fissure with a normal contiguous lobe should not force the surgeon to resort to a total resection on technical grounds Fused lobes can be taken apart safely and precisely in a manner similar to that used in segmental resection

At times when upper lobectomy has been elected as the most promising form of treatment, exploration may reveal sufficient involvement in other lobes to contraindicate lobectomy Here, the surgeon must decide whether to perform a more extensive resection or abandon resection in favor of thoracoplasty Such a decision would have to be based on the type of disease, the presence of endobronchial tuberculosis, and the status of the contralateral lung Every surgeon must finally appraise the risks involved, not only the immediate operative risk, but also the ultimate risk of the disease itself without resection

In the event that exploration reveals a well-circumscribed tuberculoma with no evidence of involvement of other parts of the lung, a local excision may be possible and if so is preferential The fate of the remaining lung is unknown, and this applies to all cases, regardles of the type of treatment or the extent of the resection In cases treated by lobectomy for a solitary tuberculoma, late studies have shown the appear-

ance of new disease in the ipsolateral lobe The overdisten tion of the remaining lobe may have predisposed to this development It is our practice now to carry out as limited a resection as possible with local removal or a segmental re section for tuberculoma

Cystic Disease—When the chest is explored for the purpose of excising a pulmonary cyst or cysts, fairly com plete knowledge of lung pathology has been furnished in advance in most instances Because of the tendency of cystic disease to be bilateral and multilobar, it is important to be as conservative as possible in its surgical treatment Em physematous cysts (blebs and bullae), solitary or multiple, are best treated by simple plication of the walls after a partial excision The clinical history and findings at times suggest that a cyst is merely the remains of a segment or subsegment after its destruction by an inflammatory process At other times the cyst seems to represent an improperly developed segment or subsegment Whenever the cyst totally involves such a surgical unit it may be treated by segmental resection Rarely has lobectomy been necessary for solitary cysts

TREATMENT OF BRONCHOVASCULAR STRUCTURES

Sequence—In the performance of a pneumonectomy, the order in which the structures are dealt with is as follows unless pathological conditions make this sequence technically impossible temporary ligature of the main bronchus, com pletion of lung mobilization, ligation of the artery, division of the pulmonary ligament, ligation of the inferior pulmo nary vein, ligation of the superior pulmonary vein, severance of the bronchus, removal of the lung mass, and finally re amputation of the bronchus at a high level The bronchus is sealed as early as possible in order to exclude infected ma terial, secretions, and debris from the remainder of the bronchial system The division of the bronchus is the last step in order to prevent contamination of the field The artery is ligated before the veins to conserve blood The

dissection moves downward from the posterior approach. If the inferior pulmonary ligament is next separated, the inferior vein comes readily into view and can be disposed of. The lung must then be reflected upward or downward to expose the superior vein, which is readily dissected and treated The field is next protected with towels to avoid soiling, and the bronchus is clamped distally just beyond the temporary ligature, divided, and cauterized. If this is carefully done, there should be no spillage. The preliminary bronchial ligature has an additional advantage for it permits removal of the lung itself before final dissection of the bronchus at a high level and the final placement of bronchial sutures The preliminary ligature also is useful in preventing air escape and dissemination of infected bronchial material via air currents during the final treatment of the bronchus

In lobectomy cases, primary temporary ligation of the bronchus is not usually feasible Pursuit of the artery in the interlobar fissure constitutes the first step. Ligation of the vein and bronchus follows

In segmental resections, the segmental artery is ligated first, and then the segmental vein and segmental bronchus.

Temporary Occlusion of the Bronchus—Before proceeding with an extensive mobilization and manipulation of the lung, it is advantageous to occlude the bronchus if it is technically possible to do so. It is important to divide the

FIG 16 Temporary ligation of left main bronchus and treatment of the pulmonary artery

a The posterior mediastinal pleura has been incised and vagal branches have been ligated.

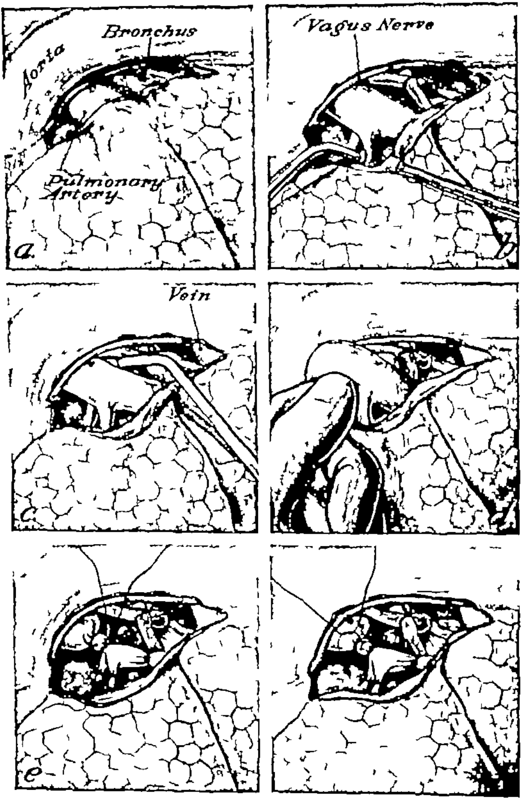
b A section of rubber tube has been placed against the membranous portion of the bronchus A temporary ligature encircles both The pulmonary artery is exposed and the posterior arterial branch is being dissected out

c The anterior surface of the artery is being dissected The apical and posterior arterial branches are clearly shown

d The final freeing of the artery has been accomplished by blunt finger dissection

e Individual branches of the main artery have been ligated distally. Two mass ligatures have been placed proximally. A transfixion suture is being placed between the mass ligatures

f The transfixion ligature is being tied a second time around the artery


Bronchus
Aorta
Pulmonary Artery
a.
Vagus Nerve
b
Vein
c
e

posterior vagal branches before the complete incision of the posterior mediastinal pleura over the hilar structures This will allow a wider separation of the mediastinal pleura and give a better exposure to the hilar structures After the posterior exposure of the bronchus the dissection can be carried downward to its inferior surface; then, after the artery has been separated, complete encirclement is accomplished A heavy braided silk ligature is used Before tying the ligature, the surgeon applies a section of catheter tubing 1 centimeter in length against the membranous portion of the bronchus, and the ligature is tied snugly (see Figure 16, a and b). The enclosed rubber tube invaginates the soft part of the bronchus against the cartilaginous portion and effects an airtight occlusion Especially in tuberculous patients, the sooner the bad lung is divorced from the good one, the less likelihood is there of contralateral spread of the disease Fortunately, in most of the tuberculous patients requiring pneumonectomy, where spill-over is most serious, the hilar structures usually are not bound down by inflammatory changes and the main bronchus can be reached and dissected with minimal manipulation of the lung itself If, however, dense adhesions, active infection, or enlarged or metastatic lymph nodes (frozen hilum) make the dissection of the main bronchus difficult, the artery should be dealt with first.

The Pulmonary Vessels—The intrapleural portion of the pulmonary artery is short, and the arterial cuff may not be long enough to place proximal and distal sutures The first arterial branches may be dissected out before the main artery is freed Distal ligatures can be placed around the branches This provides a greater space between the proximal and distal ligatures It seems important to have three sides of any great vessel exposed prior to the final dissection; then, if the vessel is injured during the course of the dissection, the thumb and forefinger may readily be applied to give control The sulcus between the superior vein and artery can readily be seen and the structures identified It has been our practice always to transfix two proximal ligatures after

an original mass ligature has been placed The distal sutures on large vessels are transfixed if these sutures have not been placed in the branches This will avoid troublesome back bleeding (see Figure 16, c f)

In cases of total resection where the dissection of a great vessel is found to be complicated because of pathological changes, it may be wise and expedient to deliberately carry the dissection to the intrapericardial level This will be necessary most frequently in performing palliative pneu monectomy for cancer Either vein or pulmonary artery on the right or left may be approached from below after open ing the pericardium It should be remembered that a ves tigial fold of serous pericardium passes from the left pulmo nary artery to the left superior pulmonary vein posterior to the left extremity of the transverse sinus This fold encloses a fibrous strand, the ligamentum venae cavae sinistrae The vestigial fold must be divided prior to placement of a mas ligature around the left pulmonary artery Also, in treatin the veins from this approach a fold of pericardium usuall is found between the two veins On the right side the peri cardium can usually be conveniently opened by a paralle incision just posterior to the phrenic nerve

Final Bronchial Closure—Permanent closure of th bronchial stump is of great importance for the ultimat success of the operation Clinical observations, broncho scopic examinations, the study of pathological specimen and a critical survey of the experimental work done in thi field have impressed us with the necessity of carrying ou the bronchial closure with the following principles in mind

1 In the performance of pneumonectomy, the bronchu should be divided as near the carina as possible, thus creatin a small bronchial pouch or eliminating it altogether Thi diminishes the amount of secretion which may later ac cumulate there High amputation of the bronchus also per mits the stump to retract well into the mediastinum and thu be covered with more loose areolar connective tissue tha if a long stump remains

2 The bronchus should be so handled that contamination is avoided or minimized Spillage of bronchial contents should be prevented. Bronchial air currents should be avoided.

3 The sutures should be placed in the bronchus so as not to interfere with its blood supply

4 The bronchus should be covered with living tissue

The cut end of the bronchus is clamped with two Allis forceps The encircling ligature and rubber tube are then removed Three mattress sutures are placed close to the carina in the axis of the bronchus and including a cartilaginous ring These mattress sutures act as a first line of defense against the strain on the end sutures of intrabronchial pressure which is increased with cough The mattress sutures flatten the bronchial stump and also decrease the size of the intrabronchial pouch The mattress sutures, so placed, do not deprive the end of the bronchus of its blood supply (see Figure 17, a-d)

Objections have been raised by many to the use of mattress sutures which bring mucosa to mucosa The placement of mattress sutures, however, does reduce strain on the end sutures, and permits a meticulous treatment of the end of the bronchus with exclusion of air currents It minimizes contamination and allows chemical cauterization of the mucosa down to the mattress suture line We feel, therefore, that the advantages of the mattress sutures offset any theoretical objections

The bronchus is now reamputated 3 millimeters distal to the mattress suture line Complete severance is not carried out immediately as the bronchial cuff is used for traction The interior of the bronchial stump is painted with a non-irritating antiseptic, such as zephiran chloride 1:1000 solution In the event that the resection is carried out for tuberculosis with extensive involvement of the main bronchial wall at the line of division, the mucosa distal to the mattress sutures is cauterized A bead of sodium hydroxide is used for this and contact maintained for ten to fifteen seconds only Care is taken to prevent its touching any tissue other

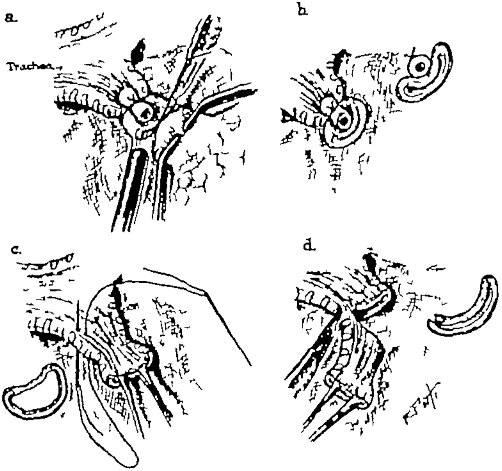


FIG 17 Drawings illustrating final treatment of the left main bronchu

a. Division of the bronchus between temporary ligature and distally place holding clamps. Note protecting gauze pad and suction tip maintained clo to the bronchial opening

b Top and lateral appearance of the cut end of the bronchus showin invagination of the posterior wall by rubber tube beneath temporary ligatu effecting air tight closure

c. Placement of mattress sutures. Two straight needles are used for eac suture. The cross section shows bronchial lumen at suture level. Note th both cartilaginous ring ends extend around to include the edge of th posterior wall The membranous wall is shorter than the cartilaginous wal

d Reamputation of the bronchus. The upper edge has not been complete divided as the bronchial cuff is being used for traction The knife blade shown dividing the upper angle of the cartilage. The cross section show bronchial lumen after placement of mattress sutures and after cartilage t has been sectioned.

FIG 17 Drawings illustrating final treatment of the left main bronchus

e Chemical cauterization of the mucosa using a bead of sodium hydroxide which is immediately neutralized with acetic acid

f Washing of the bronchial stump with normal saline solution The bronchus is tested for air leak The washings are immediately aspirated

g. Placement of end sutures

h Flap of endothoracic fascia and pleura turned down over the bronchial stump and sutured in position.

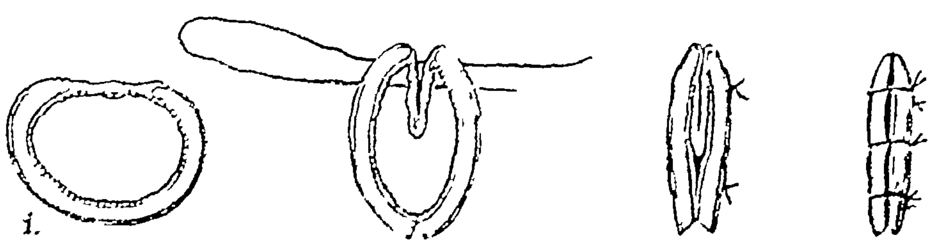


FIG 17 Drawings illustrating final treatment of the left main bronchus

i Method of main bronchial closure by vertical approximation The cartilages are fractured in their center and the membranous wall is invaginated This method is employed when the membranous portion is disproportionately narrow or when cartilages are unyielding A minimal number of sutures are required

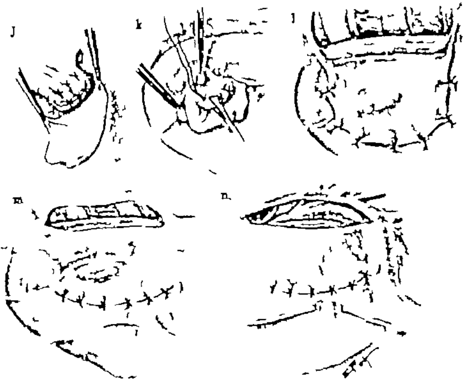


FIG. 17 Drawings illustrating final treatment of the left main bronchus.

j Use of a free graft of pleura or fascia in place of flap of endothoracic fascia and pleura as employed in (h)

k Free graft being held in place with an Allis forceps and sutures being inserted through the end of the bronchus.

l Mediastinal opening being closed with a flap of endothoracic fascia and pleura.

m. Alternate method of mediastinal closure by direct suture as employed on left side. The pleura and endothoracic fascia are released by a linear incision lateral to the aorta.

n Drawing of same step used on the right side Here the releasing incision is made parallel to the esophagus and lateral to the azygos vein

than mucosa A small pledget of gauze saturated with a 6 per cent solution of acetic acid is then applied to neutralize the alkali Cauterization of the mucosa reduces the bacterial content and also invites better cicatrization The bronchial stump is washed with saline and tested for air tightness Before positive pressure is induced the anesthetist aspirates the bronchial system in order to avoid dissemination of secretions

as the pressure is raised If the bronchial end does not easily flatten out, the last two bronchial rings are cut where their curve is greatest. Through-and-through end sutures are inserted Three or four of these will usually suffice The remaining bronchial edge for traction is then divided (See Figure 17, e-h.)

A useful variation in bronchial wall approximation should be mentioned Quite often the membranous portion of the main bronchus will be found to be narrower than average and will constitute one-third or less of the total circumference The closure can be more securely effected by dividing the last two or three cartilages in their precise mid-point, and by then suturing the ends to each other (see Figure 17, i) This suture invaginates the membranous portion between the two opposed half sections of the cartilages. A minimal number of sutures are necessary and the structures can be brought together without tension This method is also useful in older people where firm or calcified cartilages are found

A flap of endothoracic fascia and pleura is dissected from the costovertebral portion of the chest wall It is developed until its length is sufficient so that after attachment the bronchial stump will retract well within the mediastinum The flap is sutured to the bronchial stump with three additional end sutures

Sometimes we have used a variation in the reinforcement of the bronchial stump A free fascial or pleural graft may be removed from any area and sutured to the bronchial stump with three or four end sutures (see Figure 17, j-n) While the free graft is being attached, the vagus nerve is retracted The stump then retracts into the mediastinal tissue carrying with it the free graft The mediastinal pleural opening is covered either by a pleural flap dissected from the costovertebral portion of the chest wall or by suturing both edges of the mediastinal pleura When the mediastinal rent is wide, a releasing incision in the parietal pleura and endothoracic fascia is made parallel and lateral to the aorta or the esophagus. It is then possible to draw the edges of the mediastinal

be used in all tissues with the exception of the bronchus The strength and fineness of the material, its precise placement, the proper settling of knots, and the degree of tension placed upon the tissues have more to do with satisfactory results than the particular suture material used Every surgeon has a preference for material for routine use That suture material to which he is accustomed may have practical superiority in his hands.

For bronchial closure a non-absorbable material is advised For closure of the segmental bronchi and for closure of most main bronchi we prefer fine interrupted silk (size 3-0) From time to time we have given limited trial to other materials but have invariably returned to the use of silk. Its ease of handling, its high tensile strength in the finer sizes, and the minimal reaction that takes place in the tissues are all commendable features Recently in the closure of main bronchi involved in tuberculous disease we have used fine stainless steel wire (size 34) Wire sutures are more difficult to handle than silk and the setting of the knot has to be done with extreme care Kinking of the wire may prevent the knot from sliding down to its proper position Therefore the first half-knot should be pulled down without kinking the wire strand After it is properly set, a twist or rotation of the two strands for 25 or 30 degrees will temporarily hold the half-knot in position The second half-knot should be squared The wire should be cut close to the knot so that the ends are not palpable Apparently there is very little reaction to the wire sutures and they become embedded in the tissues and remain there without giving any evidence of irritation The condition of the interior of the stumps observed bronchoscopically has been consistently satisfactory

Fine silk (size 3-0) is our preference for the ligation of all vessels of the chest wall and for all sutures used in the closure of muscles, fascia, and skin Silk ligatures of the same size are also used for all hilar vascular ligation and for bronchial closure in segmental and lobar resections There is one rare exception to this practice and that is in an operation that is carried out in the presence of gross infection when soiling

of the wound is inevitable Then stainless steel wire ligatures and sutures (size 34) are used throughout the operation in the chest wall and for all phases of the intrapleural and hilar work

The costal cage is re approximated and firmly held by pericostal, subperiosteally placed ligatures of double strands of chromic catgut No 1 In the presence of gross chest wall contamination stainless steel wire sutures (size 34) are used

In the event that a subsequent thoracoplasty is to be performed with certainty or if a very hasty closure of the chest is demanded because of the condition of the patient, pericostal metal clips are used Stainless steel bands* of varying length have been designed with curved ends which fit the rib edge. These clips can be applied quickly and with ease and provide secure approximation Clips of stainless steel cause no tissue reaction and may be contained in the chest wall permanently However, for roentgenological cosmetic reasons, the clips have been used electively only in cases where the thoracic cage is to be re exposed, permitting their removal An exception to this rule is their use in emergency closure

CLOSURE

Chest Wall Reconstruction—An effort is made to rest the mechanical efficiency and integrity of the chest wall intact thoracic cage is necessary for proper lung ventilat and for the natural expulsive force of the cough mechanis As we have said before, in pneumonectomy cases an air ti closure of the thoracic cage is important Sudden loss of or fluid from the hemithorax results in sudden shifts mediastinal position It is, therefore, important to seal pleural cavity and regulate pressures periodically af manometer readings have been taken

It is well known that pain impairs the efficiency of cou Experience has shown that the inclusion of the interco nerves in pericostal sutures and an unstable thoracic c are responsible, to a large degree, for the production

* These were uggested by and developed in conjunction with Dr Emil Nacl

postoperative pain Ribs can be reapproximated with subperiosteal sutures that carefully avoid the intercostal nerves and securely hold the ribs in their proper position. The ribs to be drawn together are denuded of periosteum for about 1 centimeter at the suture site Two pericostal sutures are necessary. Notches are made in the rib edge with a small rongeur This will prevent the suture from sliding Chromic catgut No 1 is used. The ribs are then drawn together with a Bailey rib approximator (see Figure 8) or with rake retractors, and the sutures are set (see Figure 18, a) After the ribs have been secured, the pleura, the periosteum, and the intercostal muscles are sutured in a single layer. Stainless steel clips are used for rib approximation if the chest wall is to be exposed again for thoracoplasty. This method gives positive fixation and permits a rapid closure of the thoracic cage (see Figure 19).

In all cases where some lung tissue remains an air-tight closure is not obligatory or even desirable The escape of air and fluid out into the subscapular space favors re-expansion of the lobes or segments and does not interfere with primary healing In our experience we have never seen a single case where the escape of fluid from the pleural cavity has resulted in an infection of the chest wall even when the field has been contaminated. After approximation of the ribs has been effected with the two pericostal sutures, no attempt is made to completely seal the intercostal space The edge of the longissimus dorsi muscle is sutured to the intercostal tissue to close the paravertebral aspect of the thoracic cage defect Three or four sutures are placed anteriorly in the intercostal opening to prevent herniation of lung or pericardial fat in this area

The back muscles (trapezius, latissimus dorsi, rhomboidei, and serratus) are re-approximated with interrupted sutures in two layers (see Figure 20) The rhomboideus and serratus are sutured in the first layer, and the trapezius and latissimus dorsi in the second layer. It is important that the fascia of the muscle edges be re-apposed identically Two pairs of silk sutures are placed as markers on opposite sides of the mus-

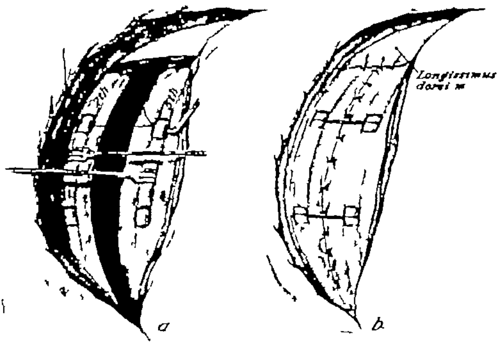


FIG 18 Drawings illustrating thoracic cage closure after pneumonectomy

a. Small areas of periosteum have been separated completely around two ribs and the outer rib edges notched for pericostal subperiosteal suture.

b The thoracic cage has been sealed in an air tight manner Interrupted sutures have been placed in the intercostal muscles and periosteal bed of the previously resected rib The paravertebral aspect of the opening has been closed by suturing the longissimus dorsi muscle edge to the intercostal muscle

cles before their division as an aid in precise re alignment

The subcutaneous fascia is drawn together with closely placed, interrupted sutures inserted so that when tied the knots lie beneath the fascial layer This layer reinforces the muscle closure and does much to prevent subsequent widening of the visible cutaneous scar It should be properly re aligned

The skin is closed with interrupted sutures after the previously placed cross hatches are re aligned Inexpensive milliner's straight needles are used They are threaded and autoclaved in advance The use of multiple needles, already threaded, makes a rapid skin closure possible and avoids multiple skin punctures by a single needle At first all the

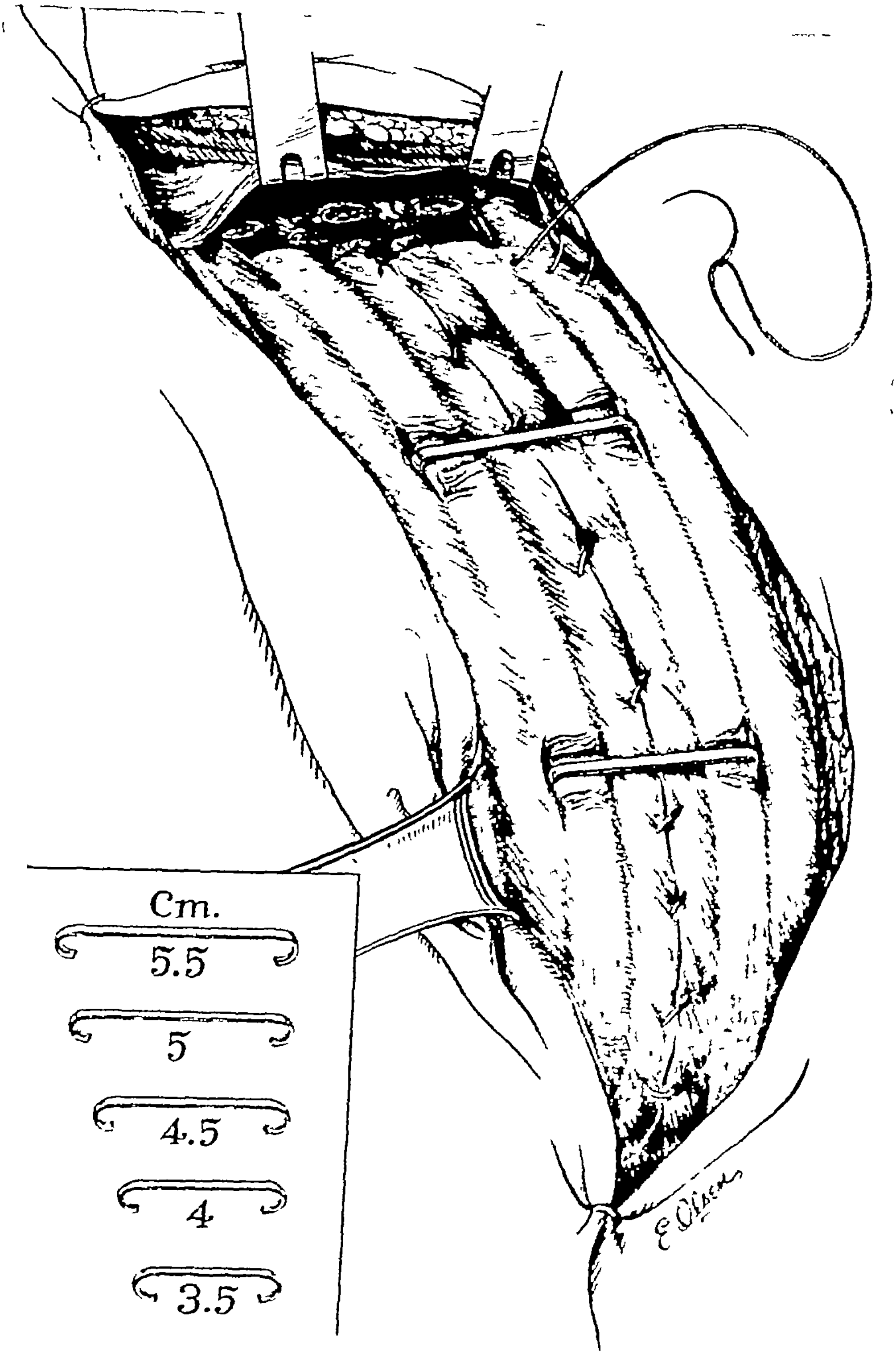


FIG. 19 Drawing illustrating the use of stainless steel clips to re-approximate the thoracic cage Clips are used routinely in closure after pneumonectomy if thoracoplasty is to follow, at which time they are removed The metal clips are hooked subperiosteally around the edges of the ribs Insert shows different size metal clips (in millimeters) This method gives positive fixation regardless of stress. Early ambulation with minimal discomfort is possible

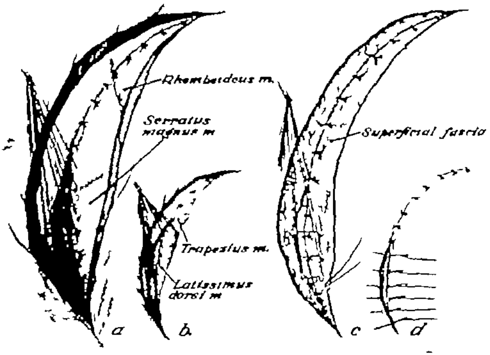


FIG. 20 Drawings illustrating closure of the soft tissues of the chest wall following resection of a lung Fascial planes of muscle have been exaggerated in order to emphasize their precise re-approximation and re alignment.

needles are inserted through both skin edges This fixes the skin in proper re alignment as the final closure is effected The assistant pulls the individual needles through as the threads are tied The suture line is covered with silver foil before the dressing is applied

Drainage—Pneumonectomy cases are closed in an air tight manner without a drain Intrapleural pressures are regulated by air aspiration or injection after manometer readings are taken When thoracoplasty, however, has pre ceded pneumonectomy, the pleural space is small These cases show sudden pressure changes with very small amounts of fluid accumulation Routinely, the pleural cavity is drained with a soft flexible Penrose type drain which is left in place for about 48 hours

In lobectomy or segmental resection cases, the primary concern is early re expansion of the remaining ipsolateral lung, and obliteration of the pleural space All these cases,

therefore, are drained for about 48 hours with one or two rubber catheters (size 26) which emerge through the anterior end of the incision (see Figure 13, b) or through separate stab wounds The draining catheters are later attached to a suction system with a negative pressure of 10 to 12 centimeters of water Higher negative pressure suction during the first 24 hours is not desirable because it may predispose to intrapleural bleeding, formation of fluid, and occlusion of catheter openings by sucking lung tissue against them before all air or fluid has been aspirated

Final Steps—At the completion of the operation, in pneumonectomy cases, intrapleural pressure is checked and regulated to the normal physiological level by means of needle aspiration of air In lobectomy cases, fluid and air are aspirated through the draining catheter and at the same time the anesthetist applies gentle positive pressure to aid in re-expansion of the remaining lung tissue

A spica type of dressing of an elastic adhesive (elastoplast) is applied to the shoulder and chest (see Figure 21) The strips are applied generally at right angles to the wound to afford relief of all tension on the wound regardless of arm or shoulder position or of motion The patient is then transferred to a bed directly from the operating table This eliminates another transfer in the patient's room A thorough endotracheal aspiration is carried out in the operating room Careful auscultation of the chest is done to make sure that the airways are free of secretions The intratracheal tube is then removed If there has been difficulty with the re-expansion of any segment or if there is any suspicion that secretions remain in the bronchial system, the patient is immediately bronchoscoped and aspirated under direct vision Seldom has postoperative bronchoscopy been necessary with our present method of management on the table We attribute this to the ease with which secretions pour out of the intratracheal tube in the face-down position, to early temporary ligature of the bronchus, thorough aspiration of the bronchial system with a catheter via the intratracheal tube,

FIG. 21 Photograph of patient with elastoplast dressing applied to give elastic support to chest and shoulder The upper strips are placed at right angles over the wound and across the shoulder to the anterior chest in such a manner that arm motion is not limited

and the conscious status of the patient during the operation

With the anesthetist, surgeon, and assistants all working to complete the final details of the operation, there is a tendency to subject the patient to too much simultaneous manipulation The various maneuvers necessary at the conclusion of the operation should be carried out gently and in sequence and not simultaneously For example, aspiration of the trachea should not be done at the same time that air is being aspirated from the chest, nor should the intratracheal tube be immediately withdrawn after the patient is turned

Before the patient is returned to his room, the blood pressure, the pulse, and the respiration should be satisfactory We prefer that the patient not leave the operating room unless he is conscious Additional blood is given if blood pressure is below 100 in patients with normal readings preoperatively After the blood pressure becomes stabilized the venoclysis is discontinued

EMERGENCY SITUATIONS

Sudden and dramatic situations may arise during the course of an intrathoracic operation that can best be described as true emergencies The dramatic changes are all concerned with cardio-respiratory difficulties It is possible to practically eliminate them by following two principles First, known factors that bring them about should be avoided. Second, at the first impending sign of these disturbances, maneuvers pertaining to the operation itself should be abruptly abandoned and all energy devoted to restoring the cardio-respiratory balance

Many years ago in the early days of visceral thoracic surgery it was considered more important to hastily finish the operation and either abandon resection or discontinue a meticulous dissection and use a tourniquet for a rapid treatment of the hilum, close the chest, and get the patient off of the table before he expired It became a race between the surgeon and the factors which operated to throw the cardio-respiratory mechanism out of balance It is now known that it is far safer not to hurry the operation itself, and that it is possible to restore normal heart and respiratory rhythm and re-stabilize the blood pressure at any time during the course of the operation The cardio-respiratory mechanism can best be kept in balance by careful attention to the factors which are known to upset this mechanism

Danger Signals and Suggestions—At no time should the blood pressure be permitted to slide down and remain for any length of time at a pre-shock level A falling pressure usually means blood loss A sudden rise in blood pressure is another warning A rising pressure means a severe degree of anoxia Blood loss can be minimized by starting the infusion of blood simultaneously with the incision and regulating its flow so that it equals blood lost If at any time the gravity flow of citrated blood is too slow as indicated by the drip, the flow can be augmented by accessory pumping This is accomplished by using a syringe, needle, and three-way adapter

which permits an assistant to draw blood from the transfusion system and force it into the venous system at any desired speed Care should be exercised in checking all bleeding points, particularly chest wall areas which are out of the direct vision of the surgeon Slow oozing from several areas can bring the patient into an unsuspected pre shock state in operations which last one, two, or more hours This is particularly true when the surgeon's attention is focused on a meticulous dissection in a different field

What is even more serious than a gradually falling pressure is a rising blood pressure which is due to a lowered oxygen content of arterial blood Almost invariably the anesthetist will find occlusion of the airways This is a mechanical problem that can be corrected The airways should be free of secretions It is the anesthetist's task to be always on the alert to test constantly the system and aspirate at regular intervals whether there are obvious signs of obstruction or not. In lobectomy cases, it is important to periodically reinflate the remaining lobes during the course of the operation In patients with low pulmonary reserve and particularly in those undergoing treatment for bilateral bronchiectasis, it may be necessary to continuously maintain a state of partial inflation of healthy segments on the side of operation This practice has permitted the successful completion of treatment for many patients in whom the deficient contralateral lung could not even temporarily carry the respiratory load The color of the tissues can be checked better by the surgeon than by the anesthetist Anything more than a momentary darkening of the blood calls for a cessation of operative maneuvers and full cooperation of all members of the surgical team with the anesthetist until proper oxygenation is assured Difficulties in maintaining proper oxygenation usually appear early in the course of the operation and often before the incision is made

The surgeon should be open minded about altering plans for continuing an operation if things are not going well Breathing must be regular and unobstructed The heart action must be satisfactory and the blood pressure level must

be brought back to a safe range A sustained elevated pressure is a serious sign and unless promptly corrected calls for an abandonment of further operative acts There is always a critical point in any operation from which there is no turning back In pulmonary resection that point is not reached until the bronchus is actually divided The pulmonary artery or even the artery and both veins may be ligated and the lung left *in situ* The chest may then be closed to continue on a later day The abandonment of the operation before the lung is removed, but after the bronchus has been divided is a conceivable situation that might be forced upon the surgeon. Development of infection would almost certainly follow In the event that the exposure itself has consumed a considerable amount of time with an excessive amount of unavoidable blood loss, the surgeon should decide early how he can stage the operation to best advantage. If staging is necessary it is better to anticipate its necessity rather than be forced into a sudden reversal of plans without the benefit of election as to where to stop If the procedure is to be divided into two stages, it is well to divide the necessary work about equally This situation arises most frequently in post-thoracoplasty resection or when infection of the chest wall complicates the picture. Here it is well to deliberately plan to appraise the situation after the lung is exposed and before any hilar dissection is carried out If it then seems best to divide the procedure, the operation should be discontinued. If one proceeds cautiously as outlined previously, it has been our experience that stage operations will rarely be necessary

Stimuli produced in the lung or hilar area involving both afferent and efferent branches of the vagus nerve (so-called vago-vagal reflexes) inhibit cardiac activity, slow its rate, and may even cause cardiac standstill Elsewhere we have mentioned the routine practice of injecting the vagus nerve at the level of the main stem bronchus using a one per cent solution of procaine hydrochloride The peribronchial tissues are also infiltrated to interrupt the branches of the pulmonary plexus The injection may be repeated later if

bradycardia is again evidenced In patients where these disturbing reflexes continue to be troublesome an intravenous injection of atropine, grains 1/150, is given Careful and gentle handling of the lung and hilar structures does more to eliminate vago vagal reflexes than any other precautionary measure Undue traction upon the lung pedicle should be avoided at all times The use of lung clamps makes it very easy to unconsciously exert too much traction on the lung root The assistants eventually find their hands on the clamps and, in their attempt to improve visibility, quite invariably exert undue traction We have found it safer to eliminate all traction clamps except for their brief application for a specific dissection

We make it a practice to interrupt temporarily the operation any time that the patient's condition is not satisfactory as shown by irregular breathing, fast breathing, rise or fall in blood pressure, bradycardia, or cyanosis The rib retractors are removed, the ribs are quickly approximated with temporary metal clips, and the wound is covered with hot saline packs The anesthetist rechecks airways, the exchange of gases, and the flow of supplementary blood If these three factors are in order, the temporary interruption of the operation will permit proper adjustments to take place

Upon occasions blood clots or debris may suddenly block the contralateral bronchus and removal by catheter suction via the in lying tracheal tube may not be successful An emergency bronchoscopy is possible but difficult to carry out during the course of an operation Seconds count and any delay may spell death In most instances when this emergency arises the chest is open The obstruction can be more quickly and positively dealt with by immediate bronchotomy The main stem bronchus is rapidly opened by slitting the membranous posterior wall and a catheter is introduced in that way for suction In the event that lobectomy is to be performed, the emergency bronchotomy should be performed if possible, upon the lobar bronchus

Cardiac Standstill—Sudden cardiac standstill occurred

in rare occasions early in our experience with resections This complication is the most serious of all and the time interval for the re-establishment of the circulation is short If the period of cessation of blood flow exceeds 3 to 4 minutes, irreversible changes in nerve tissue take place During the past two years careful attention to preventive details has provided immunity from such catastrophes In the past when cardiac standstill occurred the following steps were instituted immediately and simultaneously In approximately half of the cases it was possible to re-establish cardiac pulsations

1 Immediate manual compression of the heart was carried out so that its pumping action was temporarily taken over After each forceful squeeze, the heart was allowed to fill The rate of this action was 40 to 50 per minute.

2 The system was checked for bronchial occlusion.

3 Rhythmic positive pressure of the closed anesthetic system was applied adding only oxygen Pressure was produced with manipulation of the re-breathing bag at a rate of 15 to 20 per minute

4 An intracardiac injection of adrenalin, 1 cc of a 1.1000 solution, was given. In the future, if the necessity for cardiac resuscitation arises, adrenalin solution will be used in smaller amounts and will be injected into the aorta rather than into a chamber of the heart Dr Leo Hand has pointed out that if 5 minims of adrenalin in 20 cc normal saline solution is injected into the ascending aorta, the adrenalin will more likely find its way into the coronary artery than if a solution of less volume is injected into the heart He also warns against the use of larger doses of adrenalin because of a real danger of overexcitation and the production of circus movements A failing heart should not be too severely whipped.

Technical Accidents—Technical accidents involving the great vessels may occur regardless of how meticulous the care in dissection In palliative resection for carcinoma the vessel walls may be invaded by tumor tissue and their treatment rendered difficult Calcified hilar glands and the

changes following long standing suppurative disease may greatly complicate vessel dissection Avoidance of injury is far better than the most skillful maneuver to repair an injury Employment of the intrapericardial approach for proximal ligation should be always kept in mind In the dissection of vessels prior to their ligation it is well to dissect in such a manner that two sides of the vessels can be surrounded by thumb and forefinger for compression if the necessity arrives Peripheral ligatures can often be placed on branches prior to final dissection of the main stem of the vessel Should the vessel be torn care should be exercised not to increase the rent by hasty application of hemostats Often manual compression, flushing out the wound with saline, and aspiration of the fluid will permit the surgeon to appraise the extent of the injury The vessel may then be sutured and preserved or ligated as conditions dictate It has been found that the application of an Allis forceps to a torn main artery or vein gives better control than any type of hemostat The handle of the Allis forceps may be shifted with less danger of the blades of the instrument pulling away from the vessel wall or tearing it Twisting the handle of the Allis forceps is a very useful maneuver at times if direct application of the forceps does not stop blood flow Suture ligatures can often be placed in a through and through mattress fashion by employing straight needles Two round pointed needles are used, one on each end of the thread If multiple mattress sutures are needed, the loops are overlapped

In the performance of segmental or lobe resections, injury to the principal vessels of adjacent lobes may occur The condition under which this is most likely to happen is in resection of the left upper lobe Because of the vulnerable position of the entire trunk of the left pulmonary artery the wall of this vessel may be injured beyond repair and its ligation become necessary A decision then must be made as to total resection versus leaving the defunctionalized lower lobe in place It would seem more expedient to alter plans and do a complete resection In most instances, with the dissection of the left upper hilum so complicated that the main artery has

been injured, it is far simpler to move to the next higher level and dissect the structures of the main hilum. The patient sacrifices no more vital tissue and probably the safety factor is increased

The injury of segmental or lobar bronchi of healthy lobes during dissection in the performance of subtotal resection is of more serious importance than vascular injury The repair of bronchial walls without resulting occlusion from mucosal swelling or stricture is difficult to accomplish The opening of a bronchus also introduces the added element of infection. Any serious injury of a bronchus obligates the surgeon to immediately enlarge upon the plan of resection and include that segment or lobe whose brònchus is involved in the injury Small or minor injuries of the bronchial wall may be meticulously sutured with success An overlying graft of muscle may be useful for its sealing qualities Bronchial injuries or leaks of the cartilaginous portion are easier to repair than posterior wall injuries

Chapter IV

Intrapulmonary and Hilar Surgical Anatomy

A READY KNOWLEDGE of the bronchovascular pattern and its most common variations within the lung, lobes, and segments is essential in the modern performance of pulmonary resection In the tourniquet era, the surgeon was not concerned with the relative position of the structures in the primary or secondary hilum A meticulous dissection, with individual treatment of hilar structures, demands a more intimate acquaintance with intrapulmonary anatomy Proper adjustment of the extent of the resection to the extent of the disease requires great precision in dissection The consideration of pulmonary segments as surgical units requires the thoracic surgeon to familiarize himself with the various tertiary hila and the relative positions of bronchopulmonary segments

The description of structures in this book is undertaken within the frame of usefulness for the thoracic surgeon The arrangements of the bronchi and larger vessels and their connections in the root of the lung, in the lobar hilum, and in the interlobar fissures are described as seen in the surgical approach, and from angles familiar to and used by the surgeon The variations of interrelated anatomy of the various components of the hilum which are of practical concern to the surgeon are given The peripheral arrangements of the vessels are not considered in detail, for they have no bearing on surgical problems

This surgico anatomical study is based on patterns found in dissecting heart lung specimens and from observations made in the surgical amphitheater

Lung structure as seen at the operating table after exposure

of the hilum posteriorly through the interlobar fissures and anteriorly is illustrated

The dissections were carried out with the heart-lung specimens so placed as to duplicate as closely as possible the view encountered during operation with the patient in the face-down position For clarity's sake, the fissures have been widely separated The dissection of the anterior aspect of the lung root was done with the specimen retracted upward. The lymph nodes which normally fill the crevices between the vascular and bronchial structures were intentionally omitted in the illustrations

NOMENCLATURE

Jackson and Huber's bronchial terminology has been adopted in our clinic (see Figure 22). They have made a painstaking study of the bronchial system and have given careful consideration to other suggested names for segments They have attempted to work out a terminology which is "acceptable to the bronchoscopist, the thoracic surgeon, and the radiologist, and which will meet with the approval of the anatomist." They have chosen to use the position of the segment within the lobe as a basis for its name The use of the word "axillary" has been dropped since both upper and lower lobes have axillary surfaces, and in the upper lobe portions of two segments face the axilla The terms ventral and dorsal have also been eliminated since they could apply to segments in either lobe Jackson and Huber's selection of the name "superior" for the upper segment of the lower lobe rather than "dorsal" seems logical

We have adopted the same nomenclature for the vascular tree with the exception of the naming of the veins of the right upper lobe. Segmental arteries which accompany the corresponding bronchus can easily be given the same name as the bronchus The veins which run in the periphery of the segments, either between adjoining ones or on the pleural surface of the lung at the level of the lobar hilum, parallel a segmental bronchus on its medial or inferior aspect and

will also be named according to the corresponding bronchus The bronchovascular segmental arrangement, however, in the right upper lobe shows lack of uniformity This applies particularly to the veins, according to Boyden, and they, therefore should be identified with a different terminology than the bronchi

THE ROOT OF THE LUNG

Within the root of the lung, the following structures are found bronchus, pulmonary artery, pulmonary veins, bronchial arteries and veins, nerve plexuses, lymph nodes, lymphatic vessels, and areolar tissue These structures connect the lung to the heart and trachea On the right side, the root lies behind the superior vena cava and part of the right atrium The azygos vein lies above the root and partially circumscribes the right main bronchus The root of the left lung lies beneath the arch of the aorta and in front of the descending aorta On the anterior surfaces of both pulmonary roots are found the phrenic nerves, the pericardiophrenic arteries and veins, and the anterior pulmonary plexuses The vagus nerves posterior pulmonary plexuses, and bronchial arteries lie in the posterior aspect of the pulmonary roots On both sides at the level of the hilum, the chief structures of the pulmonary root are arranged in a similar manner Anteroposteriorly the pulmonary veins are in front, the artery in the middle and the bronchus behind From above downward, the arrangement on the left differs from that on the right On the right side, the bronchus, the artery, and the veins are found in that order On the left side, the artery is the uppermost structure, then the bronchus and the veins All these structures in the hilum are covered by the pleura The investing pleural layers come into contact at the lower border of the hilum and form the pulmonary ligament which reflects into the mediastinum at the level of the esophagus and is usually attached to the esophageal fascia The inferior pulmonary vein is enveloped by the pulmonary ligament as it reaches the hilum

THE BRONCHIAL TREE

The segmental bronchi have come to equal in surgical importance the lobar bronchus The bronchopulmonary segments have definite clinical, anatomical, and pathological characteristics Often diseased processes are limited to individual segments Accurate segmental localization can often be made by x-ray, bronchogram, and with the bronchoscope. The most common pattern consists of ten bronchopulmonary segments on the right side and eight on the left side (see Figure 22).

Bronchi of the Right Upper Lobe—The right upper lobe is divided into three bronchopulmonary segments (see Figures 22 and 23) . the apical, the anterior, and the posterior. The upper lobe bronchus arises close to the bifurcation of the trachea. It is very short and branches immediately The precise localization of tuberculous lesions emphasizes the vulnerability of the posterior, then apical segments for cavity formation Two of the subdivisions of the segmental bronchi of this lobe are of special interest. The branches of the anterior and of the posterior segmental bronchus which supply the region of the axilla are the most common sites of lung abscess in the upper lobe.

Bronchi of the Middle Lobe—The portion of the right bronchus between the orifice of the upper and middle lobe bronchi is called the bronchus intermedius It varies from 10 to 15 millimeters in length The middle lobe bronchus comes off from the anterolateral aspect of the bronchus intermedius at almost the same level as the superior segmental bronchus of the lower lobe (see Figures 22 and 23). At times, the middle lobe bronchus may arise at a slightly lower level This bronchus is usually 8 to 12 millimeters in length and then divides into its medial and lateral branches.

Bronchi of the Right Lower Lobe—Two large divisional bronchi form the lower lobe bronchus: the superior segmental and the basal bronchus The superior bronchus arises

from the posterior and lateral aspect of the main bronchus at the origin of the lower lobe bronchus and at the level of the middle lobe bronchus, or slightly above it (see Figures 22 and 23) The surgical significance of this anatomical feature deserves special comment When a lower lobectomy is being performed, the bronchus to the superior and basal segments should be divided separately in order not to ob struct or injure the middle lobe bronchus The basal divi

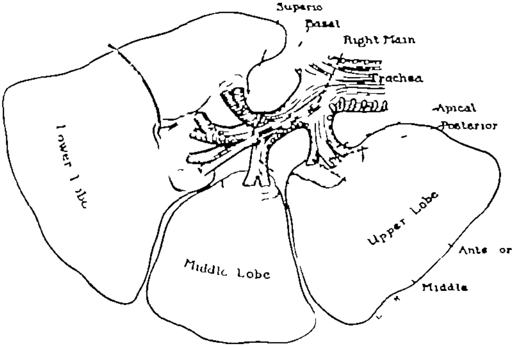
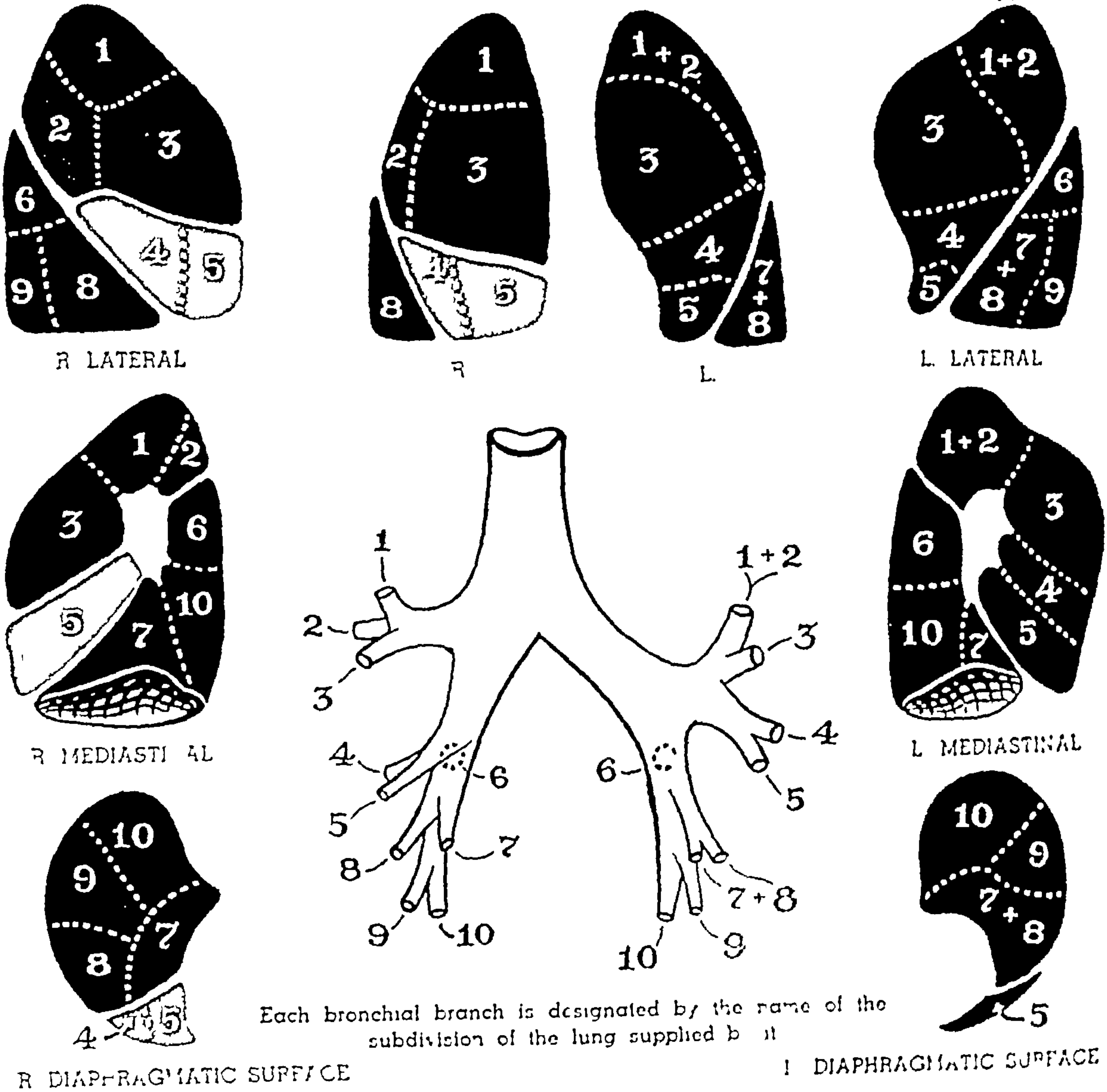


FIG. 23 Drawing from an anatomical dissection illustrating the bronchial tree of the right lung in the prone position seen from the posterior aspect The lobes have been retracted to expose the segmental bronchi

sional bronchus constitutes in reality, the prolongation of the main bronchus It has a common stem which branches into four segmental bronchi The basal segmental bronchi are the medial, the anterior the lateral, and the posterior Some authors also describe an independent subsuperior seg mental bronchus Neil and co workers have named this seg ment the "subapical" and found it to have an independent bronchus interpolated posteriorly between the superior and the basal segments and extending sometimes as far as the midaxillary line



RIGHT LUNG

LOBES	SEGMENTS	
Upper	Apical	1
	Posterior	2
	Anterior	3
Middle	Lateral	4
	Medial	5
Lower	Superior	6
	Medial Basal	7
	Anterior Basal	8
	Lateral Basal	9
	Posterior Basal	10

LEFT LUNG

LOBES		SEGMENTS	
Upper	Upper Division	Apical posterior	1+2
		Anterior	3
	Lower (Lingular) Division	Superior	4
		Inferior	5
Lower		Sup[illegible]	[illegible]
		[illegible] Basal	[illegible]
		[illegible]	[illegible]
		[illegible]	[illegible]

FIG 22 Nomenclature for the Bronchi and Lungs The topographical arrangement of the bronchopulmonary segments as adapted from Chevalier L Jackson and John Franklin Huber, Temple University School of Medicine

Bronchi of the Left Upper Lobe—The left upper lobar bronchus divides into two main divisional bronchi designated as upper and lower (lingular) divisions (see Figures 22 and 24) The upper division has an ascending course and divides into two segmental bronchi the apical posterior and the anterior bronchi The apical posterior segmental bron

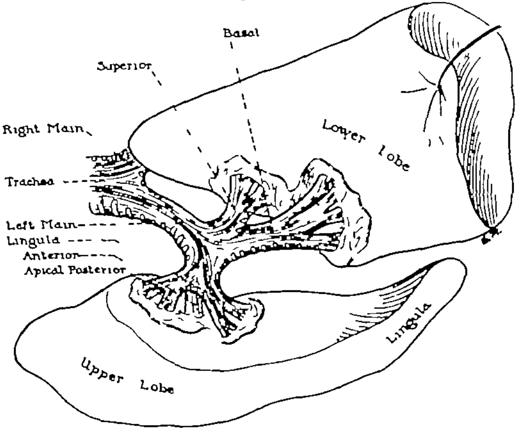


FIG 24. Drawing of an anatomical dissection showing the bronchial tree of the left lung in the prone position observed from the posterior aspect. The lobes have been retracted to expose the segmental bronchi

chus branches into two subsegmental bronchi, the apical and the posterior, considered by some authors as individual segments Tuberculosis cavities are most frequently found in these segments The anterior segmental bronchus gives off a lateral subsegmental branch which ventilates an area of clinical importance In this subsegment, abscesses of the left upper lobe are most frequently found

The inferior or lingular division is considered anatomically and clinically the counterpart of the middle lobe on

the right This divisional bronchus takes origin from the inferior aspect of the left upper lobe bronchus. The lingular bronchus has a descending and anterior course It divides into two segmental bronchi: the superior and the inferior branches. Sometimes a variation in the pattern of the segmental bronchi of the upper lobe is seen The anterior segmental branch may originate from a common trunk together with the lingular division.

Bronchi of the Left Lower Lobe—Two large divisional bronchi arise from the lower lobe bronchus, as is found on the right: the superior and the basal bronchi (see Figures 22 and 24) The superior segmental bronchus arises from the postero-lateral surface of the left bronchus about 5 millimeters below the level of the upper lobe bronchus The basal segments—anterior-medial, lateral, and posterior basal—originate from a common stem and constitute the prolongation of the left bronchus. The proximity of origin of the superior segmental bronchus to the upper lobe orifice warrants special mention In performing a lower lobectomy, it is often safer, as on the right side, to divide the basal and superior segmental bronchi separately rather than the main stem above the orifice of the superior divisional bronchus.

Some Variations in Bronchial Patterns—On rare occasions, the segmental bronchi of both lobes virtually take origin from the left main stem bronchus much in the way spokes are in relation to the hub of a wheel This appearance is due to an absence of lobar bronchi or to those which are extremely short and wide

One encounters from time to time anomalies which give freak bronchial patterns. They are recognized after bronchoscopy or complete bronchography An accessory right upper lobe bronchus may be found which takes origin from the lateral wall of the trachea slightly above the orifice of the right main stem Neil has called attention to another accessory segment (subapical) which, if present, is situated below the superior division of the lower lobe with its bronchial orifice just below that divisional opening Often bron-

chial cysts are found which have a bronchial attachment indicating the presence of supernumerary bronchial branches

A reverse situation may be found, that is, the congenital absence of a segment, lobe, or lung We recently explored the right chest of a patient for total bronchiectasis on that side The right upper and middle lobes were absent. The superior segment of the lower lobe was overdeveloped and extended almost to the pleural dome The extreme apex was opaque by x ray At exploration, this portion of the chest was occupied by a lipomatous mass Concurrently with the absence of the upper and middle lobes, the arteries and the veins of those lobes were also absent

An azygos lobe is another abnormality that may be encountered in a dissection of the right upper lobe It is not a true accessory or supernumerary lobe and there has been no fault in the development of the bronchial system The azygos lobe represents an area of the right upper lobe which has become divorced from the lobe proper by an aberrant course taken by the azygos vein The vein is found in the substance of the lung at the base of an infolding of four layers of pleura, two visceral and two mediastinal The abnormal lobe lies between this septum or abnormal fissure and the upper mediastinum Stibbe has proposed the plausible and most accepted theory as to the development of the azygos lobe. Early in embryonic development the azygos vein runs over the right apex and as the lung grows the vein is pulled down by the heart and normally slides down over the medial aspect of the lung to its position over the right bronchus If there is a slight alteration in the position of the vein or if the lung bud fails to clear the venous arch, the vein descends within the substance of the lobe It then carries with it the mediastinal pleural layer and visceral pleura which form the septum This abnormality is an important one to keep in mind for it is not infrequent Clive found the condition in 0 11 per cent of mass radiographic films of 30,000 persons and Hjelm and Hulten found it in 0.43 per cent of 3 000 films

lobe The inferior pulmonary trunk is the part of the pul monary artery which, deep in the interlobar fissure, supplies the middle and lower lobes As we shall see later, this artery also supplies the posterior bronchopulmonary segment of the upper lobe through ascending arterial branches Both divi sions of the right pulmonary artery, superior and inferior, can be identified in the root of the lung

Arteries to the Right Upper Lobe—Usually three seg mental arteries can be identified in the right upper lobe the apical the anterior, and the posterior (see Figure 25) As was mentioned before, the superior pulmonary trunk is the main supply to the right upper lobe It is the first branch of the right pulmonary artery and has a common stem which divides into two branches to supply the apical and anterior bronchopulmonary segments' arteries entering the lung in front of the right bronchus at the level of the origin of the upper lobe bronchus At its origin the superior pulmonary trunk lies behind the superior vena cava and in front is cov ered by the visceral pleura The common stem of the apical and anterior segmental arteries divides at once when it enters the lobe It is distributed to the apical segment and to the greater part of the anterior segment It is the exception to find that these two segmental arteries are the sole supply for the upper lobe It occurs in less than 10 per cent of the cases according to Appleton The third segmental artery supplies the posterior segment This artery, which is an ascending one, arises from the inferior trunk in the interlobar portion of the right pulmonary artery It is not seen in the anterior hilum This branch is also referred to as the posterior ascending artery or accessory upper lobe artery It varies greatly in size and origin According to Appleton, it may supply only a small pulmonary lobule adjacent to the hilum, or it may on the other hand, supply the whole posterior bronchopulmonary segment The segmental arteries to the right upper lobe are noted for their variation in number and position A recurrent artery is described It takes origin from the common stem to the apical and anterior segmental ar

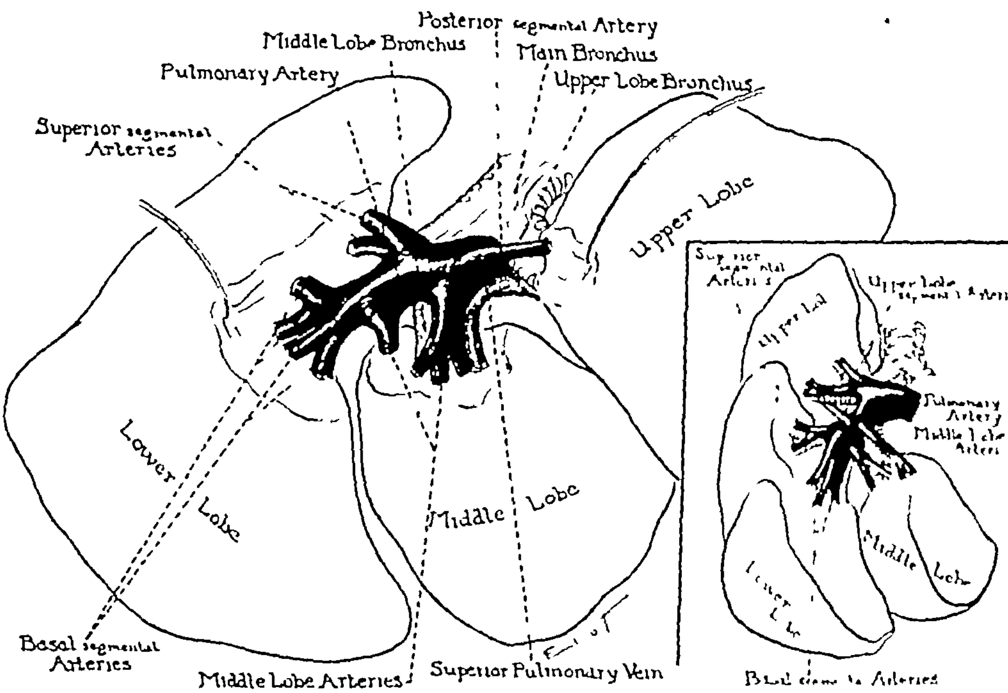


FIG 25. Drawings from an anatomical dissection illustrating the right pulmonary artery and its branches The main drawing shows the inferior pulmonary trunk with the great fissure widely exposed The lower lobe has been rotated to expose the artery more completely, making the pulmonary artery, anterior to the bronchus, appear to be posterior The pulmonary artery descends below the upper lobe bronchus The middle lobe arteries run posterior to the bronchus They arise as two separate vessels from the main trunk In this dissection the larger of the two was the uppermost and had three branches All diverging branches of the pulmonary trunk are exposed The posterior ascending segmental artery extends upward into the posterior segment of the upper lobe This branch is variable in size If large, it is the sole supply of the posterior segment If small, another vessel is usually found This is a recurrent artery originating in the apical artery The posterior ascending artery may divide in the interlobar fissure and give ascending branches to that portion of the anterior segment facing the minor fissure Exceptionally, the posterior segmental artery may arise from the superior segmental artery The only two arterial branches not visible in this approach are the apical and anterior branches The insert is a drawing of the pulmonary arterial trunk from another dissection illustrating a slight *variation* in the arterial pattern The apical-anterior arteries arise from the superior pulmonary trunk in front of the bronchus in the anterior hilum *Note also* the posterior ascending segmental artery arising from the anterolateral aspect of the artery opposite the middle lobe arteries and just above the superior segmental artery This specimen reveals the most common type of middle lobe arterial arrangement. The largest arterial branch is the medial segmental The basal artery is anterolateral to the bronchus in the interlobar fissure

teries or from the apical branch Its course is posterior and above the upper lobe bronchus and it supplies a portion of the posterior bronchopulmonary segment

Appleton has made an outstanding contribution to the knowledge of the arterial supply of the bronchopulmonary segments of the right upper lobe From his studies he states that the apical bronchopulmonary segment receives its main supply from the apical artery The part of the segment adjacent to the anterior segment is not uncommonly supplied by a branch of the recurrent artery The anterior bronchopulmonary segment is supplied by the anterior artery, a branch of the superior trunk or common stem artery to the apical and the anterior segments It is interesting to note that sometimes this segment receives an anterior ascending artery from the inferior pulmonary trunk in the interlobar portion of the pulmonary artery The posterior bronchopulmonary segment blood supply is derived from the posterior ascending arterial branch from the interlobar portion of the main pulmonary artery or inferior trunk This segment is also very often supplied by recurrent branches of the apical segmental artery and less frequently by branches derived from the anterior segmental artery Exceptionally it receives a branch from the middle lobe arteries or from the superior segmental artery of the lower lobe

Inferior Pulmonary Trunk (Arteries to the Lower, Middle, and Upper Lobes)—The inferior pulmonary trunk constitutes the inferior division of the pulmonary artery and supplies the middle and lower lobes and, in addition, gives off branches to the upper lobe The inferior pulmonary trunk is found anteriorly in the root of the lung This artery lies below the upper trunk of the pulmonary artery and runs downward and laterally into the interlobar fissure between the upper lobe bronchus and the main bronchus In the interior pulmonary hilum, the artery is crossed in front by the superior pulmonary vein (see Figure 26) and the apical anterior segmental vein Only a small portion of the artery is above the vein and at that level the artery lies beneath the

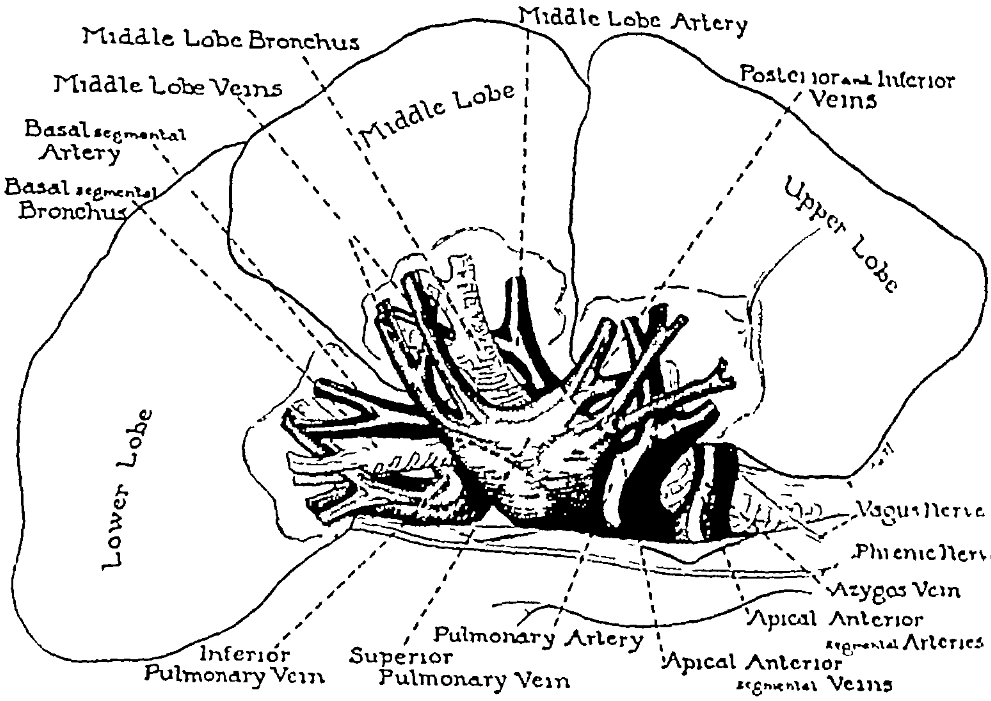


FIG. 26 Drawing from an anatomical dissection illustrating the right pulmonary root from the anterior aspect The structures of the hilum have been dissected for some distance peripherally. The pericardium has been reflected slightly The phrenic nerve runs anterior to the root of the lung between the mediastinal pleura and the pericardium The superior vena cava lies in front of the pulmonary artery. The azygos vein runs above the artery and right bronchus Only a small portion of the right bronchus above the apical-anterior artery is visible from this approach The branches of the apical-anterior artery occupy the highest position in the hilum in front of the upper lobe bronchus The pulmonary artery lies superior and posterior to the superior pulmonary vein as they emerge from the mediastinum Soon it is covered almost completely by the superior vein except for a portion of its superior trunk and a small portion of its inferior trunk The apical-anterior segmental veins cross the anterior arterial branch before they enter the superior pulmonary vein Upon deeper dissection the posterior and inferior veins can be found These veins separate the upper bronchus from the inferior pulmonary arterial trunk and then cross the base of the interlobar fissure Two veins from the middle lobe enter the superior pulmonary vein at its lower margin anterior and inferior to the middle lobe bronchus Upon deeper dissection the middle lobe artery is found superior and posterior to the bronchus The main trunk of the inferior pulmonary vein is not well exposed through this approach because it lies slightly posterior to the superior pulmonary vein Both veins form a crotch into which the arteries and bronchi fit, and upon deeper dissection, we find the artery and the main bronchus behind and slightly below it The tributary veins to the inferior pulmonary vein show in this drawing for the lower lobe has been lifted and rotated

pleura The artery lies anterior to the intermediate bronchus The posterior and inferior veins of the upper lobe separate the artery from the anterior segmental bronchus of the upper lobe The artery is at first anterior to the bronchus, but upon entering the lung and descending toward the lower lobe, it comes to occupy an anterolateral position in relation to the bronchus This artery, in the depth of the fissure, lies beneath the pleura immediately behind the junction of the oblique and horizontal fissures

Arteries to the Middle Lobe—The arteries to the middle lobe arise from the interlobar portion of the pulmonary artery and from its anterior aspect (see Figure 25) Usually they are found two in number, one to each bronchopulmonary segment, medial and lateral Sometimes the artery to the middle lobe can be seen to originate from a common trunk which divides frequently into two or three major branches In these instances, very frequently, a smaller accessory middle lobe artery is found supplying the medial bronchopulmonary segment This accessory branch also originates from the anterior aspect of the interlobar portion of the pulmonary artery 5 to 10 millimeters below the common trunk to the middle lobe arteries The arteries to the middle lobe, deep in the interlobar fissure, lie posterior to the corresponding bronchi and slightly above them (see Figures 25 and 26) The medial segmental artery supplies the mediastinal surface of the lobe and the part of the lobe adjacent to the medial interlobar surface Sometimes, the medial artery may cross the intersegmental plane and supply the adjacent portion of the lateral bronchopulmonary segment. The lateral segmental artery supplies the remaining portion of its segment Exceptionally, small branches from the middle lobe or its medial segmental divisional artery are found which supply a small portion of the anterior interlobar surface of the right upper lobe

Arteries to the Right Lower Lobe—The arteries to the right lower lobe follow the corresponding bronchi more

closely than those to the upper and middle lobes and almost duplicate the bronchial pattern Branches to the superior segment and basal segmental arteries all originate in the inferior pulmonary trunk, some in the interlobar portion of the pulmonary artery deep in the fissure, and some almost within the lung substance (see Figure 25)

The first branch arising below or at the level of the middle lobe artery, but from the posterolateral aspect of the interlobar portion of the main pulmonary artery, is the superior segmental artery This artery is slightly posterior to the main bronchus and runs superoanteriorly to its corresponding segmental bronchus This segmental artery divides within the lung into two or three branches to supply the segmental subdivisions Sometimes, two separate segmental arteries, both originating from the interlobar portion of the main artery, are found This arrangement, however, is not common. In rare instances, we have found an ascending arterial branch originating from the superior segmental artery. This branch, when present, supplies the posterior portion of the interlobar surface of the upper lobe Boyden has called attention to an arterial ramus originating in the superior segmental artery which extends downward in a paravertebral direction as far as the lower third of the lower lobe

The arteries to the basal segments arise from the inferior pulmonary trunk, either in the depth of the oblique interlobar fissure immediately below the arteries to the superior segment and to the middle lobe, or from the inferior portion of the pulmonary artery within the lobe itself. The inferior portion of the pulmonary artery lies anterolaterally to the bronchus in the lobar hilum, and the various segmental arterial branches follow the corresponding bronchi very closely Four segmental arteries are recognized and arise independently from the anterior and posterior aspects of the pulmonary artery Sometimes a different pattern is encountered The pulmonary artery almost within the lobe may divide into two trunks, anterior and posterior, which immediately subdivide into two smaller branches to supply the four bronchopulmonary segments In this way, the medial

and anterior basal arteries have a common stem, and the lateral and posterior basal have another stem

Left Pulmonary Artery—The left pulmonary artery, from its origin until it gives off the first arterial branch to the left upper lobe, curves in a posterolateral and slightly upward direction The artery lies above the left bronchus and the superior pulmonary vein It lies inferior to the aortic arch and vagus nerve Anterolaterally, the artery is covered by the mediastinal pleura and is crossed over by the apical posterior segmental vein Posteromedially, the artery crosses the main bronchus in a posterior and upward direction The artery ascends over the superior surface of the main bronchus arching over the left upper lobe bronchus and then enters the interlobar fissure (see Figures 27 and 28) In contrast to the right side, where the artery is anterior to the bronchus, on the left side the artery passes around and behind the upper lobe bronchus The arrangements of the structures in the upper lobe hilum in both anteroposterior and inferosuperior directions are vein, bronchus, artery

Arteries to the Left Upper Lobe—There is a certain similarity in the arterial supply of the left upper lobe and of the right side if we consider the arterial supply of the right upper and middle lobes as equivalent to the arterial supply of the left upper lobe The arteries to the upper lobe, however, may vary in their origin, arrangement, and number We have found them most frequently from four to six in number arising from the pulmonary artery independently as short stems At other times the segmental arteries have been found to have common trunks The apical posterior trunk has two branches for the apical posterior bronchus, and the anterolingular trunk has three branches, one for the anterior segmental bronchus and two for the lower division of the left upper lobe bronchus (lingula) (see Figures 27 and 28)

The apical posterior segmental artery arises from the superior or convex surface of the pulmonary artery It has a common trunk that is very short almost sessile, and soon

divides into two branches: the ascending or apical and the posterior segmental arteries. These two branches sometimes originate independently. The ascending apical artery originates from the anterosuperior surface, and the posterior branch originates from the posterosuperior surface of the main pulmonary artery, almost in the interlobar fissure The anterior segmental artery arises in the interlobar portion of

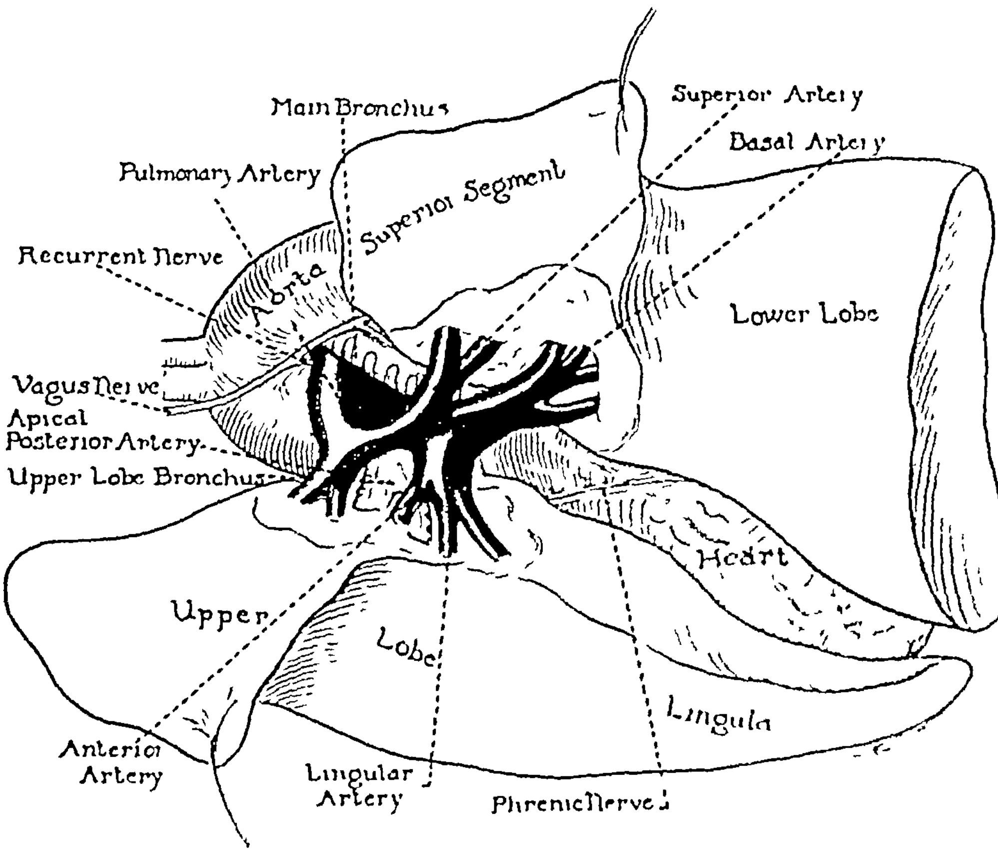


FIG 27 Drawing of an anatomical dissection illustrating the left pulmonary artery and its branches with the lobes widely separated observed from the interlobar approach This particular dissection shows the most common arterial pattern The main pulmonary artery emerges from the root of the lung anterior to the main bronchus and as it arches above and behind the upper lobe bronchus the artery courses downward and forward deep in the interlobar fissure As the artery bends over the upper lobe bronchus it gives off its first branch, the apical-posterior artery to the upper lobe. It courses through the fissure and large branches arise from its medial and lateral aspect diverging toward the upper and lower lobes. The artery to the superior segment arises at a higher level than the arteries to the anterior and lingular segments The artery terminates in the lower lobe with three or four arterial branches for the various basal segments

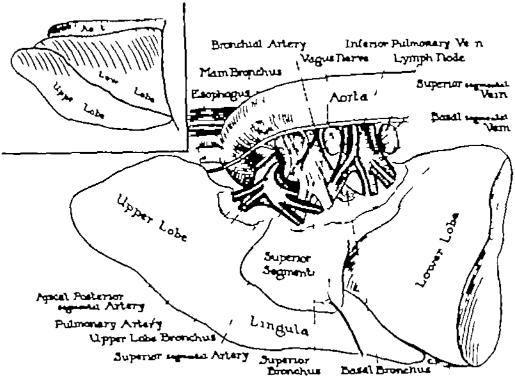


FIG. 28. Drawings of an anatomical dissection illustrating the left pulmonary root seen from the posterior aspect. Insert shows the arrangement of the lobes and their fissures at the initial exposure with the patient in the prone position. In the main drawing the mediastinal pleura has been opened and the lung has been permitted to fall forward All of the structures which have surgical significance have been dissected and are labeled. The vagus nerve runs posterior to the lung root contributing branches to the pulmonary plexus. The recurrent nerve leaves the vagus nerve at the inferior edge of the aortic arch and turns back lateral to the ligamentum arteriosum to en circle the aorta The left bronchial artery is variable in size and in position It arises usually from the first portion of the thoracic aorta and reaches the posterior wall of the bronchus by a short direct course anterior to the vagus nerve. The pulmonary artery is anterior to the main bronchus and only that portion of the artery that arches over the upper lobe bronchus before entering the fissure is shown in this drawing The apical-posterior arterial segmental branches arise from the superior convex surface of the pulmonary artery The arterial branches to the superior segment arise superior to their re spective bronchi. The main artery enters the fissure after it has arched around the upper lobe bronchus. The main bronchus and the lower lobe bronchi are easily approached through the posterior hilum. Between the main bronchus and the inferior pulmonary vein there is a triangular space usually concealed by lymph nodes. The pericardium lies in front of this space. The inferior pulmonary vein is contained in a pericardial reflection All the tributaries to the inferior pulmonary vein can be identified They emerge posterior to the bronchi.

the pulmonary artery as a branch of the anterolingular arterial trunk or independently from the main artery. According to Appleton, the anterior segmental artery may occasionally arise anteriorly before the left main artery arches over the upper lobe bronchus. The lingular artery arises in the interlobar fissure below or at the level of origin of the superior segmental artery to the lower lobe (see Figure 27) The common arterial trunk for the lingula divides into two branches for the superior and inferior lingular bronchopulmonary segments Occasionally, they are seen arising as independent branches We have already mentioned that they also may originate from a common trunk with the anterior segmental artery The lingular artery usually arises after the pulmonary artery has arched over the bronchus and lies slightly below and posterior to the lingular bronchus deep in the interlobar fissure

Arteries to the Left Lower Lobe—All the arterial branches to the lower lobe arise from the interlobar portion of the pulmonary artery (see Figure 27). The highest arterial branch of the lower lobe is the artery to the superior segment Its level of origin is, as we have already mentioned, higher than the origin of the lingular arteries The superior segmental artery lies in the lobar hilum anterior and superior to the corresponding bronchus It soon branches into two smaller arteries for the subdivisions of the segment Sometimes these two branches arise independently from the pulmonary artery at some distance from each other According to Boyden, there may be a third small branch which overlaps the basal segments in supplying the middle third of the vertebral portion of the lower lobe The arteries to the various basal segments lie anterolaterally to the bronchi in the hilum and follow these very closely into the lung substance There are usually four arterial branches for the basal segments, one for each segment: anterior, medial, lateral, and posterior basal. The anterior and medial basal arteries, the same as their respective bronchi, may originate from a common arterial trunk which soon divides

THE PULMONARY VEINS

The relationship of the veins to the bronchopulmonary segments shows a very different pattern from that of the arteries and bronchi Whereas an artery is closely related to its corresponding bronchus and, therefore, is centrally located within the segment, the veins course peripherally beneath the pleural surface and those which are deep within the lung substance follow the intersegmental plane These deep veins collect blood from adjacent segments Anomalies in the various tributary branches to the main pulmonary veins, superior and inferior, are much more frequently seen than anomalies of the arteries Communicating veins cross adjacent areas of the lobes when the fissures are incomplete or fused Even in the presence of complete fissures, veins can be found to cross from one lobe to another collecting blood from adjacent interlobar surfaces In performing a segmental resection or in separating fused lobes, the communicating intersegmental and interlobar veins will require ligation

Right Superior Pulmonary Vein—The right superior pulmonary vein is formed by all the tributaries from the upper and middle lobe veins (see Figure 26) In the hilum of the lung the superior pulmonary vein lies in front of the inferior trunk of the pulmonary artery and on entering the pericardium the vein is almost entirely below the main right pulmonary artery

Veins of the Upper Lobe—The nomenclature of the veins of the upper lobe does not follow the one we have adopted for the segmental bronchi because the veins are not strictly segmental in distribution The three main tributaries which can readily be dissected are the apical anterior, the inferior, and the posterior veins

Apical Anterior Vein—The course of the apical anterior vein is mostly superficial underneath the pleura and receives tributaries from the apical and anterior

segments In the hilum, its two main tributaries can be seen coursing down from their corresponding segments The apical-anterior segmental vein in its descending course crosses over the anterior segmental artery which lies behind and then reaches the superior pulmonary vein at its lateral and superior margin (see Figure 26)

Inferior Vein—The inferior vein runs along the inferior margin of the upper lobe It is a superficial vein and is found in the interlobar surface between the upper and middle lobes (see Figure 26) The inferior vein collects blood from the lower portion of the anterior segment and reaches the superior pulmonary vein in its lateral aspect below the apical-anterior segmental vein and in front of the posterior vein. It usually joins this vein to reach the superior pulmonary vein

Posterior Vein—The posterior vein emerges from within the lung substance It is deeply situated and in the hilum courses in a posterior position to the arteries and bronchi of the upper lobe (see Figure 26) It collects blood from the areas adjacent to the apical-anterior and apical-posterior intersegmental planes where it runs At the hilum, the posterior vein is concealed by the apical-anterior segmental vein at the line of reflexion of the pleura

Veins of the Middle Lobe—The veins of the middle lobe are two in number, the medial and the lateral segmental, and drain their corresponding bronchopulmonary segments They reach the superior pulmonary vein as a single trunk or separately. In the pulmonary hilum, they are medial and slightly inferior to the middle bronchus and join the superior pulmonary vein at its lower margin (see Figure 26)

Veins of the Right Lower Lobe—The inferior pulmonary vein is situated below the superior vein and is slightly posterior to it (see Figure 26) The inferior pulmonary vein cannot be seen easily in the anterior hilum because it is partially concealed by the inferior lobe The inferior pul-

monary vein is formed by all the segmental tributaries from the lower lobe

Two groups of veins should be considered the tributaries from the superior segment, and the tributaries from the basal bronchopulmonary segments The superior vein collects

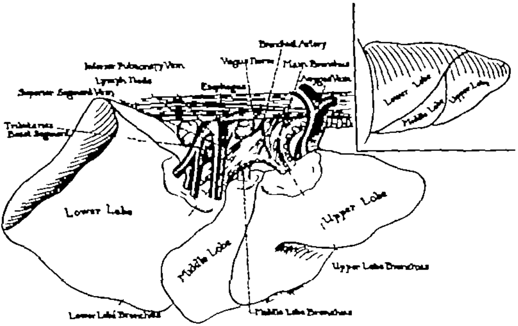


FIG. 29 Drawing from an anatomical dissection illustrating the right pulmonary root in prone position seen from the posterior aspect. Insert shows the arrangement of the lobes and their fissures after initial exposure of the lung with patient in the face-down position In the main drawing all of the lobes have been separated and permitted to fall forward. The pulmonary artery has been omitted intentionally The vagus nerve runs posterior to the bronchus on the esophagus and gives small branches to the pulmonary plexus The azygos vein is the uppermost structure in the root of the lung and arches over the right main bronchus ending in the superior vena cava The right bronchial artery is variable in size and in position. This artery may originate directly from the aortic arch or from the intercostal or one of the esophageal arteries. The bronchial artery divides into small branches which follow the bronchi and may sometimes run along with the vagal branches. The bronchial veins are not shown. They are tributary to the azygos vein but they are not easy to identify during dissection and are of no surgical importance Note that in this position a large proportion of the right main bronchial system comes into view The inferior pulmonary vein lies below and slightly anterior to the main bronchus yet most of its tributaries cross the inferior bronchi posteriorly The trunk of the inferior pulmonary vein is short and contained in a pericardial reflexion The superior segmental vein crosses behind the basal bronchus and reaches the inferior pulmonary vein at the superior margin of this vein.

blood from the superior segment by means of two or three branches which emerge from the lobe, cross the basal bronchus posteriorly, and join the inferior pulmonary vein as a single branch at its superior and posterior margin (see Figure 29) The basal veins, three or four in number, emerge from the lobe between the segmental bronchi joining the inferior pulmonary vein separately or in one or two common trunks (see Figure 29) The lowermost basal vein is the branch from the medial basal segment and is the first branch encountered after completing the division of the inferior pulmonary ligament

Left Superior Pulmonary Vein—As on the right side, the left superior pulmonary vein lies in the hilum anterior and inferior to the artery (see Figure 30). This vein receives all the tributaries from the left upper lobe.

Veins of the Upper Lobe—The veins of the upper lobe are all superficial at the hilum in contrast to the right side where, as we have already seen, there is an important deep posterior branch Three or four trunks enter the superior pulmonary vein (see Figure 30) These trunks, at the hilum, can be found anterior and inferior to their corresponding bronchi These superficial and anterior trunks collect blood from the anterior and mediastinal surfaces of their segments The central and posterior portions of the segments are drained by veins which run in the intersegmental plane, but are tributaries of the anterior trunk An apical-posterior vein collects blood from the segment of the same name This vein is formed by two branches—apical and posterior—which join the superior pulmonary vein as a single trunk at the level of the superior and lateral margin of the vein (see Figure 30). During its descending course, the apical-posterior vein crosses the posterior artery which lies behind In the hilum, this vein lies in front of and below the corresponding segmental bronchus The anterior vein drains the anterior segment It is formed by two tributaries—anterior and posterior—which join before entering the superior pulmonary vein

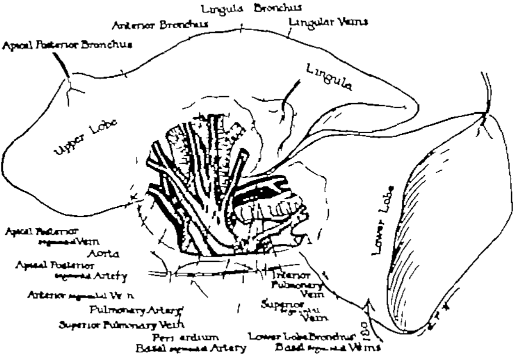


FIG. 30. Drawing of an anatomical dissection illustrating the left pulmonary root observed from the anterior aspect with the patient in the prone position. The lung has been lifted up The surgically significant structures have been dissected The pericardium has been reflected slightly The phrenic nerve runs anterior to the root of the lung between the mediastinal pleura and the pericardium. The pulmonary artery runs along the left and inferior aspect of the aorta. The apical posterior segmental artery appears arising from the superior and convex surface of the main artery before the main artery bends behind the upper lobe bronchus. The superior pulmonary vein lies anterior and inferior to the artery and upon deeper dissection the bronchus is found The apical posterior segmental vein crosses over the posterior arterial branch of the apical-posterior artery before joining the superior pulmonary vein at its superior lateral margin The segmental veins are all superficial, anterior and slightly inferior to their respective bronchi Between both main pulmonary veins there is a crotch where the bronchus can be seen. The inferior pulmonary vein lies below and slightly behind the superior pulmonary vein It is less obscured than on the right but is better visualized through the posterior approach. In this drawing the lower lobe has been rotated to give better exposure to vascular structures. Upon deep dissection the artery is found on the lateral and anterior aspect of the bronchus Because of the rotation of the lobe, the artery appears superior and posterior to the bronchus. The superior segmental vein is not completely exposed in this view Only anterior basal segmental veins can be seen

below the apical posterior vein (see Figure 30) The posterior tributary to the anterior vein runs in the inter antero

6. The inferior pulmonary ligament
7. The inferior pulmonary vein

The lung is permitted to fall forward and the azygos vein comes into view. This vein is used as a landmark to start the incision of the posterior mediastinal pleura which extends downward toward the inferior pulmonary vein The vagal branches to the posterior pulmonary plexus are dissected out and ligated This step will afford a better exposure of the posterior aspect of the pulmonary hilum and will also allow dissection of the mediastinal pleura medially and laterally The right main bronchus which emerges below the azygos vein is readily identified by inspection and palpation The first major step in performing the pneumonectomy is the temporary ligature of the bronchus. The right main bronchus is short and it may be safer, therefore, in some cases, to place temporary ligatures around the upper and intermediate bronchi separately (see Figure 31, Insert b). However, if technically expedient, it is preferable to place the temporary bronchial ligature around the main bronchus. The ligature can be placed around the main bronchus with less delay and with less danger of injury to the posterior ascending artery The main bronchus is dissected out by blunt dissection For this purpose a right angle clamp and gauze pledget are used. The lymph nodes and connective tissue are stripped away gently from the membranous portion and the anterior surface of the bronchus By opening and closing the instrument which is maintained always against the bronchial wall, the separation can be effected without injury to the pulmonary artery. Blunt dissection with the index finger passing in front of and the thumb behind the bronchus often aids the dissection. If inflammatory changes make the bronchial dissection a difficult or hazardous preliminary step, this should be accomplished after the pulmonary artery and veins have been treated

Mobilization of Upper Lobe and Ligation of Superior Arterial Trunk—The next step after the main bronchus has been temporarily ligated is the dissection of the artery to the upper lobe which lies in front of the bronchus (see Figure

31) With the patient in the face down position, the preferential approach to the hilum being from its posterior aspect, the sequence of treatment is as follows the artery to the upper lobe is ligated first, and then, after the superior pulmonary vein has been divided, the lower arterial trunk is ligated (see Figure 32, Insert) The preliminary dissection of the artery below the origin of the first branch provides a higher level to which the surgeon may retreat if the vessel is injured in the course of dissection The upper lobe is

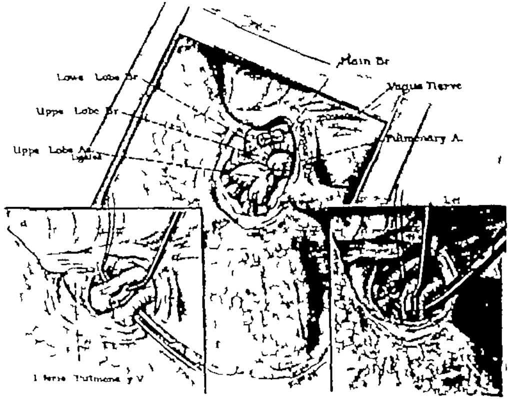


FIG. 31 Drawings of a right pneumonectomy illustrating hilar exposure with the patient in the prone position. Insert (a) shows placement of temporary bronchial ligature and rubber tube for invagination of posterior wall of the bronchus. The ligature encircles the main stem. Insert (b) shows a variation in site of placement of the temporary bronchial ligature. The intermediate bronchus has been ligated and the upper lobe bronchus is being tied. The main drawing shows the superior aspect of the hilum with a temporary occluding ligature on the main stem bronchus and the dissection of the superior pulmonary arterial trunk completed The subdivisions of the apical and anterior branches have been tied separately *for the distal ligation* The common apical anterior stem (superior pulmonary trunk) has been ligated proximally

mobilized, exposing important mediastinal structures. The superior vena cava and the phrenic nerve which runs on its lateral surface are in full view The vagus nerve is clearly seen coursing diagonally across the upper mediastinum. Beneath it the innominate artery and trachea can be palpated The azygos vein is a landmark for the pulmonary artery since this artery emerges into the pleural cavity inferior to the vein The upper lobe is retracted inferiorly and posteriorly, exposing the supero-anterior aspect of the hilum The *superior pulmonary trunk or common arterial stem for the* apical and anterior segments of the upper lobe is dissected out in the periphery where it divides, one branch to the api-

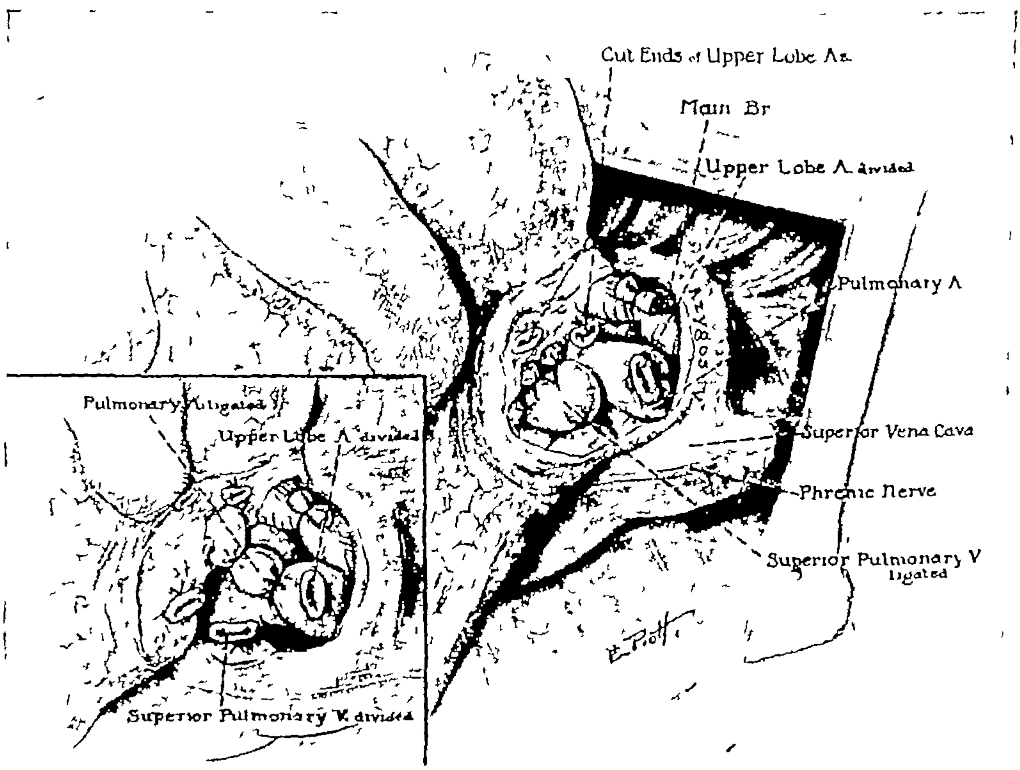


FIG 32 Drawings of a right pneumonectomy illustrating hilar exposure with the patient in the prone position In this view the upper lobe is held up to expose the anterosuperior aspect of the hilum The main drawing shows the superior pulmonary vein dissected out and ligatures placed The distal ligatures are on the tributaries and the proximal ligature is on the main venous trunk Just above and behind the superior pulmonary vein the inferior trunk of the pulmonary artery begins Note cuff of ligated superior pulmonary trunk (upper lobe artery). Insert shows the superior vein divided and the inferior trunk of the artery ligated and ready for division

cal segment and another to the anterior segment. The apical anterior veins cross in front of the artery and sometimes should be ligated first in order to provide better exposure of the artery

Ligation of Superior Pulmonary Vein—The anterior aspect of the lung is freed from the pericardium and costal attachments The anterior hilum is exposed and the mediastinal pleura is incised posterior to the phrenic nerve The superior pulmonary vein which lies anterior and inferior to the artery is exposed It should be remembered that the vein is contained in a pericardial reflexion and care should be exercised not to enter the pericardium under ordinary circumstances In the performance of palliative pneumonectomy for cancer, however, it may facilitate the treatment of the veins to deliberately open the pericardium, as suggested by Allison The vein and its three main tributaries are exposed by sharp and by blunt dissection Since the common trunk is short, we usually place distal ligatures on the branches and proximal ligatures on the main vein (see Figure 32)

Ligation of the Lower Arterial Trunk—After the superior pulmonary vein has been divided, the retraction of the lung in a posterior and inferior direction is maintained The pulmonary artery comes into view in front of and slightly lateral to the bronchus By blunt dissection the posterior surface of the artery is more completely separated from the bronchus The proximal ligatures are placed either above or below the previously ligated upper lobe branch, whichever location is most convenient (see Figure 32, Insert) The distal ligature can usually be set 1 to 1 5 centimeters lower down Later on with the lung out of the way it may be desirable to re ligate the artery at a higher level in cancer cases (see Figure 33, b)

Ligation of the Inferior Pulmonary Vein—The lung is allowed to drop forward again The posterior aspect of the hilum has already been exposed The inferior pulmonary vein lies below the bronchus and in the upper portion of the pulmonary ligament (see Figure 33) The lung is freed from

the diaphragmatic surface and the pulmonary ligament is divided In cancer cases it may be expedient and wise to open the pericardium and ligate the vein there, as suggested before in connection with the superior vein This maneuver is most frequently used when there is actual invasion of the vein by tumor or when the size of the tumor mass makes extrapericardial ligation unsafe

Amputation of the Bronchus—The lung is now solely attached by its bronchus. Two right angle clamps are placed on the bronchus distal to the previous temporary ligature of the bronchus Before the bronchus is divided, the pleural cavity should be adequately protected from soiling by the placing of gauze pads around the bronchus, and by keeping the suction tip constantly applied at the line of division of the bronchus The bronchial artery may have been included in the previous temporary ligature; if not, it should be dissected out and ligated separately at the level where the permanent closure of the bronchus will be effected (see Figure 33, a) The reamputation and closure of the bronchus has been described in the chapter on "General Considerations Pertaining to All Resections" (Chapter III) Again it should be emphasized that the final point of division of the bronchus should be high On the right side it is easily possible to palpate and visualize the angle between the right and left main stem bronchus in the infracarinal area The mattress suture line is made so that it runs in an oblique direction, higher laterally than medially This keeps the line of amputation as nearly flush with the lateral wall of the trachea as possible and helps to eliminate a bronchial pouch The large size of the right main stem bronchus and the strength of the cartilaginous rings at this level make it more difficult to approximate the membranous and cartilaginous walls than at any other site Calcification of the rings increases the difficulty of closure Partial incision and fracture of two or three rings aids in bronchial wall approximation without suture tension The mattress suture line should be carefully tested for air leak and the closure checked again after the end sutures have been placed (see Figure 17)

Division of the Right Phrenic Nerve—After the pneumonectomy has been completed, the phrenic nerve is divided between ligatures which include the phrenico pericardial vessels (see Figure 33, b) The immediate elevation of the right diaphragm is desirable for undue cardiac rotation and displacement is prevented The vertical diameter of the right hemithorax is also greatly reduced Gastrointestinal or cardio-respiratory disturbances have not been noted in right

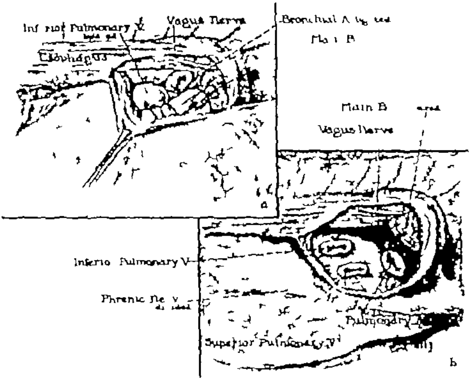


FIG. 33 Drawings of a right pneumonectomy

a Drawing of the posterior hilum with mediastinal pleura separated. The pulmonary ligament has been divided and the inferior vein dissected Distal ligatures have been placed around the basal and superior divisions and the proximal ligature around the main trunk The ligated bronchial artery is exposed

b Drawing of the arrangement of the stumps of the hilar structures. Note their related positions. The superior pulmonary vein is the most anterior and the bronchus the most posterior The cuff of the main pulmonary artery is shown Although the artery was divided originally after separate ligation of the superior and the inferior trunks it was re ligated at a higher level and reamputated

sided pneumonectomy cases where the diaphragm has been permanently paralyzed

Retrograde Sequence—Altered local conditions in the hilar area, inflammatory changes, or tumor infiltration may have so fused all the structures that dissection is extremely difficult or apparently impossible

An abandonment of the routine sequence of treatment of the various structures and substitution of a retrograde sequence may be necessary The path of least resistance is then followed, the surgeon disregarding the desirability of ligating arteries before veins or of dividing the bronchus as the last step to avoid contamination of the field during hilar dissection Whichever structure yields to dissection with the least difficulty is tackled first In most cases, the following plan will be successful

The first step is the division of the pulmonary ligament Once the ligament has been divided, the basal tributaries of the inferior vein are dissected free and ligated distally The superior vein is ligated also peripherally The proximal ligatures are placed either on the main vein or on the branches depending upon the length of the main trunk

The mediastinal pleura over the posterior hilum is incised The vagal branches are then ligated If the bronchial artery is easily isolated at the point where the artery applies itself to the under surface of the bronchial wall, it is ligated If not, the bronchial artery is included in the bronchial sutures No attempt is made to encircle the bronchus with a preliminary ligature The postero-inferior wall of the bronchus can be exposed from below without danger of injury to the pulmonary artery or the superior pulmonary vein as these structures are on its opposite side The bronchus is divided halfway across The cut portions are grasped with an "Allis type" forceps The division of the bronchus is then completed from within its lumen (see Figure 34) This reverse procedure permits bronchial division without the necessity of a supero-anterior dissection in the vicinity of the vascular elements There is greater likelihood of contamination by this method but with the use of the aspiration tip the

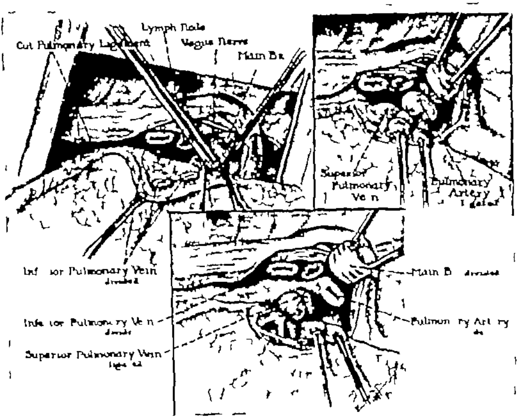


FIG 34. Drawings of a right pneumonectomy illustrating the retrograde technique used when structures of the hilum are so firmly fused that the routine sequence of dissection is impossible. The main drawing shows exposure of the posterior hilar region The inferior pulmonary ligament and vein have been divided The bronchus is in the process of being divided without previous ligation or superior and anterior dissection

a. The stump of the bronchus is being held up with Allis forceps and the pulmonary artery has been exposed and ligated Note that a proximal ligature has been placed on the main trunk and distal ligatures on the superior and the inferior divisions. Note the bulge of the superior pulmonary vein just in front and below the artery

b The superior pulmonary vein has been dissected and ligatures placed. The bronchial stumps are being retracted with Allis forceps. The related positions of all hilar structures are clearly shown The main bronchial stump will be reamputated at a higher level

exposed bronchial mucosa is kept clean Mattress sutures are then put in immediately and the mucosa beyond the line of suture sterilized with chemical cauterization (sodium hydroxide)

After the bronchus has been disposed of, the vein and the artery are ligated either individually (see Figure 34, Inserts

a and b) or *en masse* After all the bronchovascular structures have been dealt with, the remaining pleural and mediastinal attachments of the lung are separated and the lung is lifted from the chest In most instances the bronchus will require reamputation since it is difficult to carry out its division at the preferential high level at the time of the initial hilar dissection. In rare instances the hilar structures have been found to be virtually frozen together by dense fibrous tissue and at times calcific deposits This situation has been encountered in long-standing bronchial tuberculosis associated with suppurative disease. If the hilar structures resist all efforts at dissection from any approach, the surgeon, rather than abandon excisional therapy, may resort to mass treatment of hilar structures Through-and-through steel wire or silk mattress sutures are inserted Straight round-pointed skin needles are used, each end of the suture being threaded with a needle to facilitate the placement of the mattress suture The sutures are alernately reversed so that the knots are tied on both the posterior and the anterior surface of the hilum Each mattress suture is slightly overlapped to ensure positive control of all areas The technique is similar to the outmoded tourniquet method in that it secures the vessels and bronchi together This type of mass ligation has an advantage over the tourniquet method It creates a shorter and less bulky stump because the closure is effected in a linear rather than in a circular manner After the lung has been amputated the exposed mucosa of the bronchus is destroyed by chemical cauterization and the edges of the hilar stump are pulled over the end with interrupted wire sutures

Usually, even in the most difficult cases, a partial dissection of the hilum can be done The remainder of the hilum is then managed by the retrograde dissection method or by mass ligation

Left Pneumonectomy—The components of the left primary hilum which require dissection and treatment are the same in number as on the right side.

The lung is allowed to drop forward and the border of the

lung is retracted to expose the posterior aspect of the pulmonary hilum. All the posterior vagal branches to the pulmonary plexus are ligated and divided (see Figure 35). The mediastinal pleura is incised from below the arch of the aorta to the inferior pulmonary vein.

Ligation of the Main Bronchus—The bronchus lies posterior and inferior to the artery. The posterior aspect of the bronchus can be dissected out with ease from its surrounding peribronchial glands and areolar connective tissue. The main point of danger is the dissection of the anterior aspect of the bronchus because at the level of ligation the bronchus is

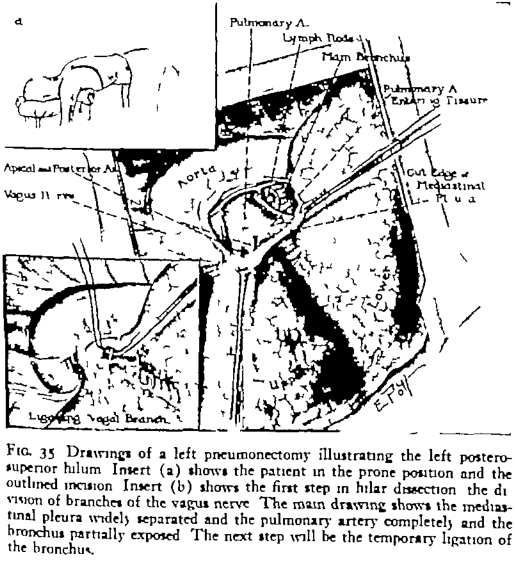


FIG. 35. Drawings of a left pneumonectomy illustrating the left postero-superior hilum. Insert (a) shows the patient in the prone position and the outlined incision. Insert (b) shows the first step in hilar dissection, the division of branches of the vagus nerve. The main drawing shows the mediastinal pleura widely separated and the pulmonary artery completely and the bronchus partially exposed. The next step will be the temporary ligation of the bronchus.

almost entirely surrounded by vessels and the pericardium is in close relation to it The descending trunk of the pulmonary artery encircles its superior and posterior surfaces The vein is in front and the pericardium adheres to it below Blunt dissection with the index finger passing in front of and the thumb behind the bronchus will assist in separating it from the artery The bronchus may be retracted posteriorly and downward The reflexion of pericardium can often be visualized and sharply dissected. If the connective tissue between the artery and the bronchus is unyielding and difficult to separate, it may be safer to expose the superior aspect of the hilum, dissect out the arterial branches, and dispose of the artery first

Ligation of the Pulmonary Artery—The upper lobe should be mobilized, exposing the antero-superior aspect of the lung hilum The artery runs beneath the aortic arch It is anterior and superior to the main bronchus After the upper lobe has been mobilized, important structures of the superior mediastinum come into view These are the subclavian artery, the vagus and the phrenic nerves, and the aortic arch The intrapleural portion of the main pulmonary artery is short It is safer and more expedient, therefore, to dissect the common trunk to the posterior apical segment and the remainder of the main trunk (see Figures 35 and 36, Insert) and place, in that way, two distal ligatures By blunt and finger dissection the areolar mediastinal tissue surrounding the artery is freed and the proximal ligatures are placed. The separate distal ligatures eliminate the necessity of placing additional suture ligatures on the lung side and the distance between proximal and distal ligatures is increased

Ligation of the Inferior and Superior Pulmonary Veins—Before the veins are treated, it is necessary to complete the division of all peripheral attachments of the lung and to free the pulmonary ligament, provided the contralateral bronchial system is protected from spill-over during manipulation by preliminary main bronchus ligation. If it has not been possible to so occlude the main bronchus, the treatment

of the veins and then the bronchial division can precede extensive mobilization of the lung. The lung is permitted to drop forward, and the posterior aspect of the hilum is exposed. The inferior pulmonary vein can readily be identified below the main bronchus. Peripheral ligatures are placed on the tributaries and proximally around the main trunk.

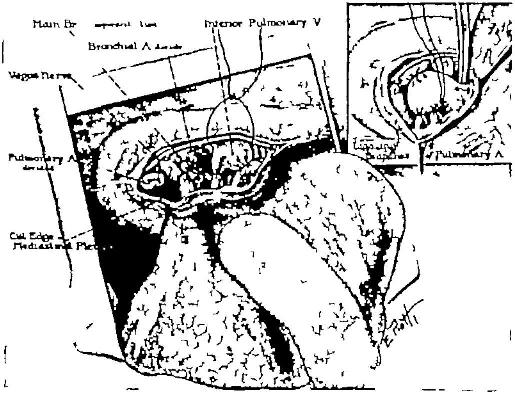


FIG. 36. Drawings of a left pneumonectomy illustrating the posterior hilum. Insert shows the pulmonary artery being ligated. Separate distal ligatures are placed around the apical-posterior branches and the main artery below these branches. The main drawing shows the stump of the main pulmonary artery, the temporary ligature about the main bronchus, and the inferior pulmonary vein being ligated.

Care should be exercised not to enter the pericardial reflexion which extends out above the vein and below the bronchus. To expose the superior pulmonary vein, the assistant retracts the lung upward and backward. The vein lies anterior and inferior to the artery and superior to the inferior vein. Here again the pericardium extends over the vein

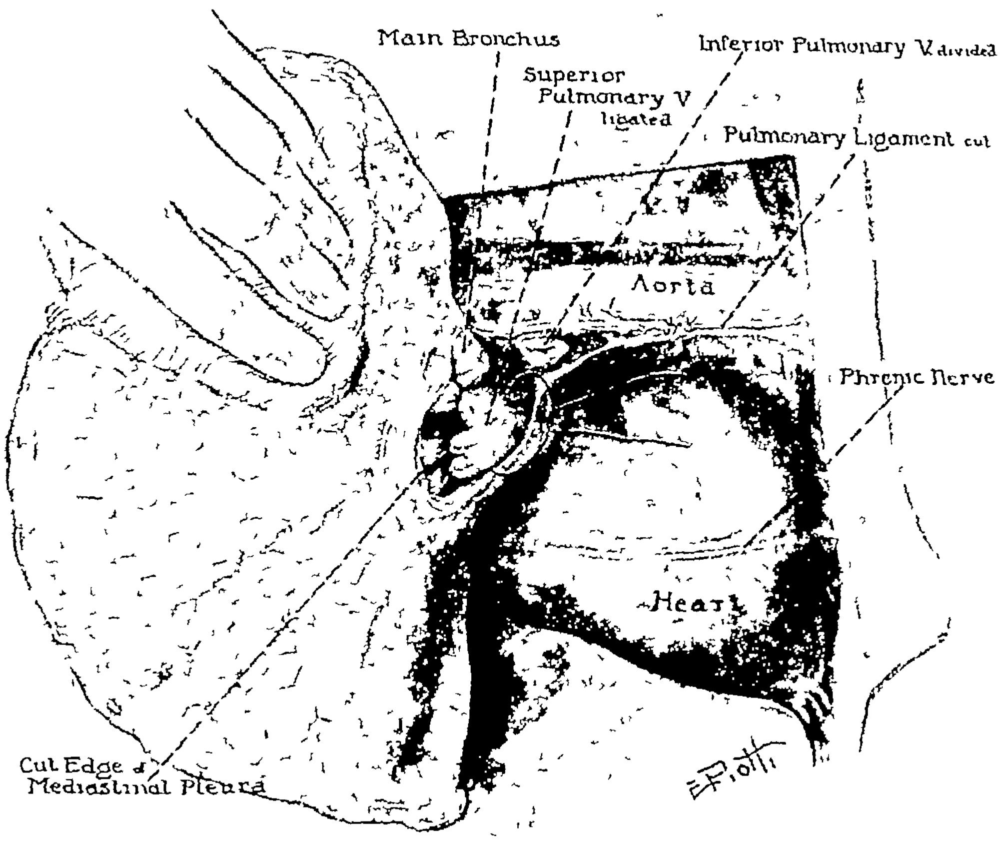


FIG 37 Drawing of a left pneumonectomy illustrating exposure of the anterior aspect of the hilum as seen from below with the lung held up The tributaries of the superior pulmonary vein have been ligated and the suture around its trunk is ready to be tied Note cuff of divided inferior pulmonary vein which is posterior and inferior to the superior vein

The main tributaries should be isolated and ligated separately after the margin of the lung has been wiped away Centrally the ligatures are placed around the main trunk (See Figures 36 and 37) In carrying out palliative resection for cancer it may be advantageous to deliberately open the pericardium and ligate one or both veins at that level

Amputation of the Bronchus—The lung is now attached only by the bronchus The technique of amputation of the bronchus is similar to the one applied on the right The left bronchus is longer than the right facilitating all the maneuvers for its isolation and treatment The bronchial artery if easily identified should be ligated separately (see Figure 36)

LOBECTOMY

Right Upper Lobectomy—The components of the secondary hilum which require dissection and treatment are

1. The superior pulmonary arterial trunk with branches to the apical and the anterior segments
2. The posterior ascending artery, a branch of the inferior pulmonary trunk

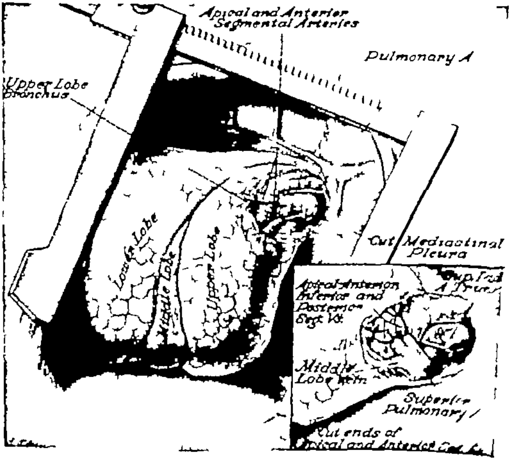


FIG. 38. Drawings of a right upper lobectomy illustrating the trea... the arteries and veins of the lobe In the main drawing the upper ... been mobilized and permitted to drop forward Proximal and distal ... have been placed on the apical and anterior segmental arteries ... instances it is convenient to place the proximal ligatures on the ... pulmonary trunk. Insert shows the anterior hilum after the upp... been lifted up and retracted posteriorly The apical anterior ar... posterior segmental veins (tributaries to the superior pulmonary ... been ligated separately The lowermost tributary to the superior ... vein is the middle lobe vein and has been preserved

3 The tributaries to the superior pulmonary vein, the apical-anterior, the inferior, and the posterior.
4 The apical, the anterior, and the posterior segmental bronchi

Mobilization—The lobe should be mobilized in order to expose the supero-anterior portion of the pulmonary hilum. This step is carried out in the same way as has been described in the right pneumonectomy. The azygos vein is a guiding landmark for the artery After the upper lobe has been retracted downward and backward, the supero-anterior aspect

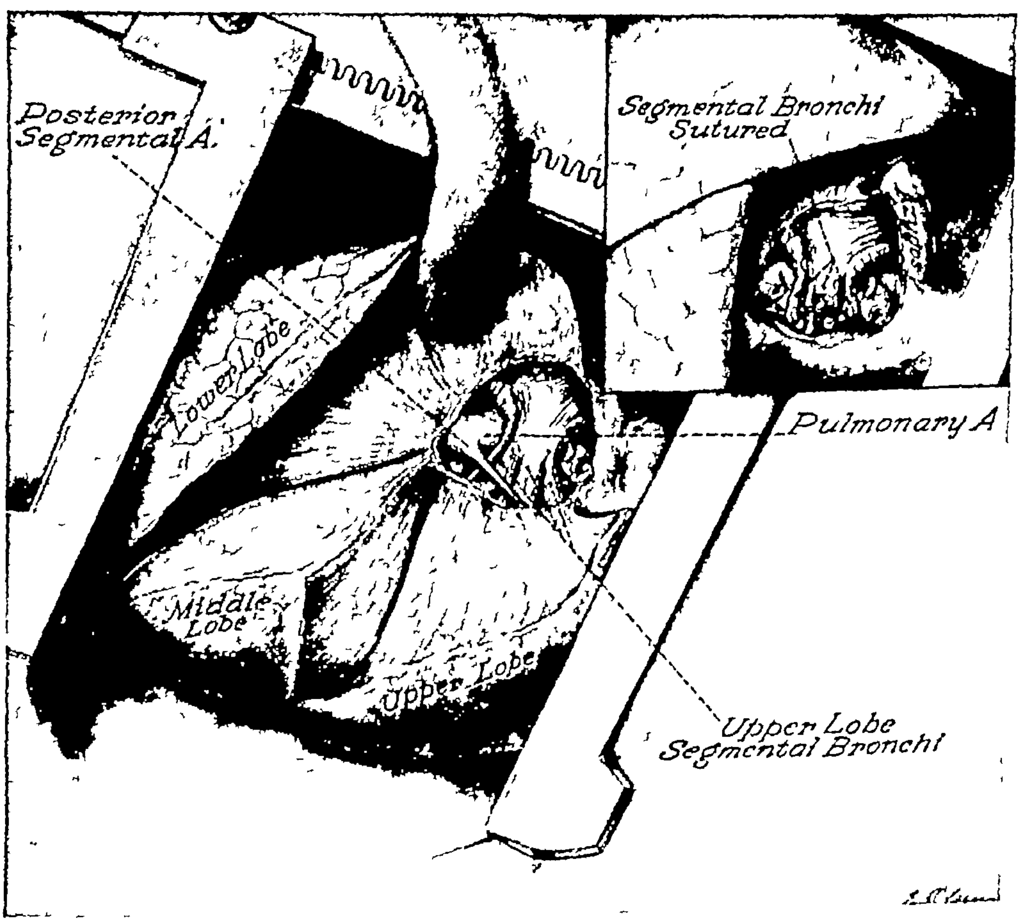


FIG 39 Drawings of a right upper lobectomy illustrating the interlobar step and the final appearance of the hilum after the lobe has been removed The main drawing shows both fissures widely developed, the posterior segmental ascending artery and the apical, anterior, and posterior segmental bronchi exposed Insert shows the three segmental bronchial stumps which have been closed individually. Note the relationship of the upper lobe bronchus to the superior and inferior trunks of the pulmonary artery.

of the hilum is exposed The superior pulmonary trunk with its two branches is the uppermost structure lying in front of the upper lobe bronchus in the root of the lobe The arterial branches are dissected out separately and ligated peripherally Proximally a mass ligature is placed on the common stem for the two arterial branches, or separate ligatures are placed on each branch (see Figure 38)

Anterior Step—The upper lobe is retracted backward in order to expose the superior pulmonary veins Only the apical anterior and postero inferior venous tributaries should be ligated The other tributaries of the superior pulmonary vein are the middle lobe veins and injury of them should be carefully avoided The proximal and distal ligatures should be placed on the branches (see Figure 38, Insert) The apical anterior vein crosses over the anterior segmental artery which runs behind At times it may be safer to ligate the vein first and then the anterior segmental artery

Interlobar Step—The portion of the oblique fissure between the upper and lower lobes should be developed in order to expose the posterior ascending segmental artery (see Figure 39) We have already mentioned elsewhere that this segmental artery is variable in size and also in origin It may be crossed over by anomalous veins The dissection of the posterior segmental artery is one of the most important steps and sometimes the most difficult operative procedure in the performance of a right upper lobectomy It has been found that in cases where the oblique and horizontal fissures are fused or incompletely developed, dissection of the posterior segmental artery is more safely done in a retrograde manner

Retrograde Technique—After the arteries and the veins to the apical and the anterior segments have been ligated, the segmental bronchi are tied temporarily with an encircling mass ligature and then divided separately (see Figure 40) The lobe is turned over and down The lower lobe is infiltrated and the demarcation line between the lobes becomes evident The contiguous surfaces of the upper and lower

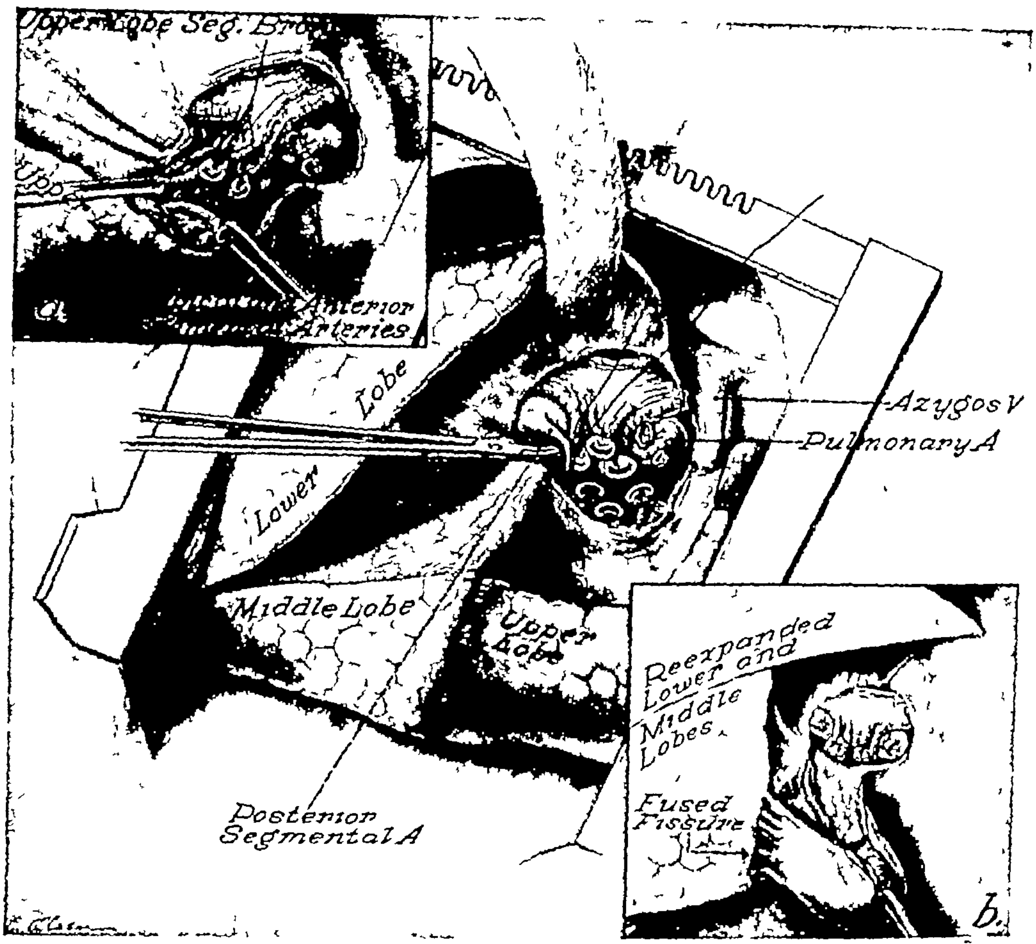


FIG 40 Drawings of a right upper lobectomy illustrating a retrograde technique of hilar dissection used when lobes are fused or hilar structures bound by inflammatory changes In Insert (a) the apical and anterior segmental arteries and posterior and apical segmental bronchi have been divided The anterior segmental bronchus has been prepared for ligation The main drawing shows further development of the secondary hilum after all bronchi of the lobe have been divided The posterior ascending segmental artery has been dissected out and is ready for ligation Insert (b) shows preparation for separation of the upper from the middle lobe The lobes which remain have been inflated and the line of demarcation between the upper and middle lobes has been located The separation of these two lobes will be done in a retrograde manner similar to that used in the development of an intersegmental plane The superior pulmonary vein is not shown. It is disposed of either before or after the dissection of the fissure

lobes are separated by sharp dissection Some small veins may have to be ligated The oblique interlobar fissure is thus exposed. The interlobar portion of the pulmonary artery lies deep in the fissure covered by the visceral pleura Usually the branching of the artery can readily be seen Any artery

which is found to enter the upper lobe from this region is the ascending posterior artery On very rare occasions another small anterior ascending artery will be discovered After the posterior segmental artery has been ligated, the upper lobe is completely detached except for variable anchorages to the middle lobe With great frequency the horizontal fissure is found to be incomplete or absent. The line of cleavage between the lobes is then developed after the lung has been inflated by means of positive pressure (see Figure 40, Insert b) The upper lobe which has been divorced from the bronchial system remains collapsed The middle lobe inflates and the line for separation is easily followed The dissection and separation is done without the use of clamps on lung tissue, as in the removal of individual segments Communicating veins may be found and require ligation Bronchial and pulmonary arterial branches do not cross the interlobar plane where there is an undeveloped fissure. The denuded surface of the middle lobe is not sutured This is unnecessary and interferes with re expansion

Upper Lobe Bronchus—Preferentially, the bronchus is sutured at the level of the segmental bronchi (see Figure 40, Insert b) We have found this to be safer than trying to place mattress and end sutures in the lobar bronchus The lobar bronchus may have a short stem, and the sutures may encroach upon the main bronchus Sutures placed extremely close to the main stem bronchus may produce an edematous reaction with varying degrees of obstruction This may cause difficulty in the re expansion of the middle lobe or superior segment of the lower lobe

Middle Lobectomy—The components of the secondary hilum which requires dissection are

1 One or two middle lobe arteries which arise from the inferior pulmonary trunk
2 The lobar bronchus, a short common trunk or two segmental divisions
3 The middle lobe vein or veins, tributaries to the superior pulmonary vein

The Chest Wall Approach—The face-down position and the posterolateral approach to the right hemithorax are preferred for this resection as for others For quite some time after the anterior approach for other types of resection was abandoned in favor of the posterolateral method an exception was made in resection of the middle lobe and an anterior, submammary incision was used. Many surgeons who use the conventional side position routinely for most intrathoracic explorations continue to make an exception in anticipated resections of the middle lobe It is true that the adherent surface of the middle lobe presents itself immediately in the anterior wound However, after its liberation or if the pleura is free, the lobe and hilum fall away to create a deep field. Undue traction may be necessary to accomplish the hilar dissection The most serious objection to the anterior approach is that after exploration a more extensive resection than originally planned may be required. Often a resection of one basal segment or an anterior segment in addition to the resection of the middle lobe is necessary Occasionally, a malignant process will be found when the chest is opened under a diagnosis of bronchiectasis and total removal of the lung found necessary The surgeon must be prepared to alter plans of resection easily and safely. The use of a universal approach for all types of lung resection ensures freedom of action

Interlobar Approach to Artery and Bronchus—The bronchovascular structures to the middle lobe can be approached through the interlobar fissure The hilar portion of the oblique fissure is developed The fissure between the lower and middle lobes is almost always well developed The interlobar portion of the pulmonary artery is exposed (see Figure 41) At that level the artery can be seen giving off divergent arterial branches for the lower and middle lobes The middle lobe artery or arteries have a downward and forward course They arise opposite the superior segmental artery We have found two arteries to the middle lobe with more frequency than one artery Before placing proximal ligatures on the artery, it is well to dissect out its branches

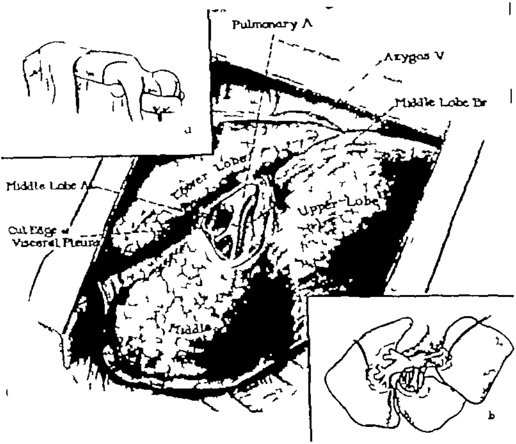


FIG. 41 Drawings of a right middle lobectomy illustrating interlobar exposure and dissection of arteries of the middle lobe Insert (a) shows the prone position of the patient with the incision outlined Insert (b) shows the right pulmonary arterial arrangement from the interlobar approach The circle includes the working area shown in the main drawing The main drawing shows the great fissure widely separated at the level of the origin of the minor fissure. A portion of the pulmonary artery has been dissected and arteries of the middle lobe have been identified The artery may be found at a slightly higher point than is shown here. The artery at its origin may parallel the bronchus and be just above it. Note that the inferior of the two comes off the main trunk in a low position placing it close to the basal arteries. This vessel is not constant

first Exceptional cases may be found where the middle lobe artery gives ascending branches to the upper lobe These branches may be the only source of supply to the posterior bronchopulmonary segment of the upper lobe, and should therefore be avoided in the ligature Immediately on deeper dissection the middle lobe bronchus appears as it lies anterior and slightly inferior to the artery (see Figure 42) A tempo-

rary mass ligature is placed around the lobar bronchus or around the two segmental bronchi if they come into view in the beginning of the dissection.

The Vein—The lobe is retracted upward and rotated clockwise 90 degrees The middle lobe vein comes into view after the mediastinal pleura has been divided below and on the anterior surface of the middle lobe hilum Care should be taken to dissect in this area with caution as the principal trunk of the superior vein must not be injured In

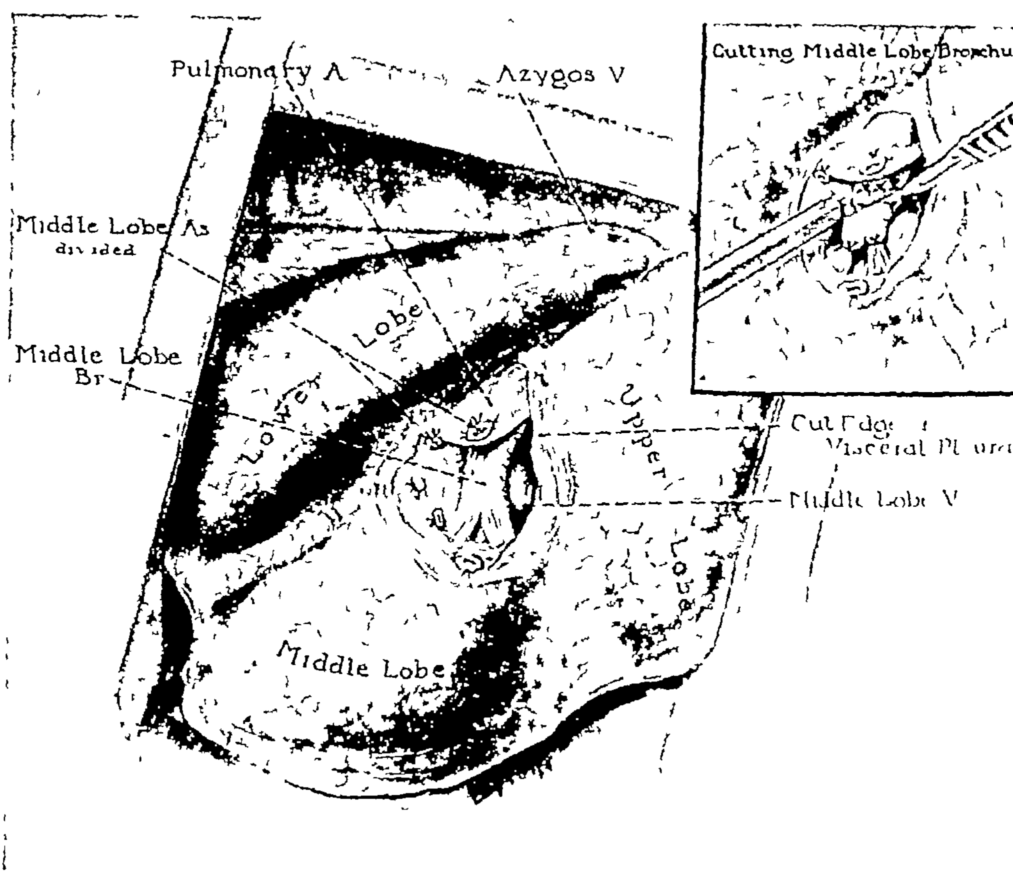


FIG 42 Drawings of a right middle lobectomy illustrating further dissection of the interlobar area The arteries of the middle lobe have been divided The posterior aspect of the middle lobe bronchus and its two segmental bronchi are shown A branch of the vein is seen posterior to the lateral segmental bronchial division just before it swings forward and downward After the great fissure below has been completely developed the middle lobe vein comes into view in front of the bronchus Insert shows the final treatment of the bronchus. It is being divided after mattress sutures have been placed. The next step will be inflation of the upper and lower lobes, and finally, completion of the separation of the lobe along the fissure lines will be effected

the event of an undeveloped fissure, no attempt should be made to find and ligate intercommunicating veins between the middle and upper lobes until later in the dissection

The Bronchus—The middle lobe bronchus is divided and the stump closed It should be remembered that the bronchus originates at the same level as the superior segmental bronchus It should therefore not be sutured too close to its main orifice If the middle bronchus stem is long enough to allow the placement of end sutures, the common stem of the

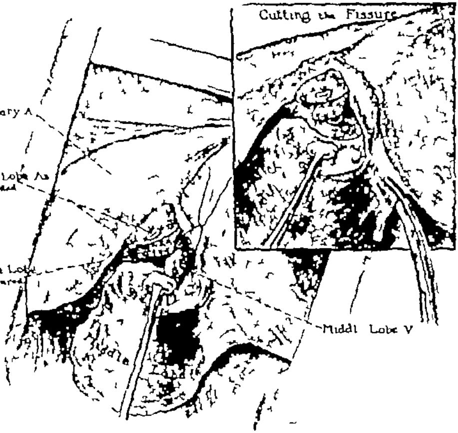


FIG 43 Drawings of a right middle lobectomy illustrating treatment of the vein and the final division of the minor fissure. The major fissure has been completely separated below An Allis forceps is making gentle traction on the distal bronchial stump This exposes the middle lobe vein which is being ligated Insert shows the arrangement of the hilar structures of the middle lobe after their division The artery is posterior the vein anterior and the bronchus in between the two. The lobe, now solely attached by tissue at the base of the minor fissure is being cut with scissors.

bronchus is closed Otherwise it is safer to close both segmental bronchi separately.

The Minor Fissure—The final step is the dissection of the minor fissure, or more properly the separation of the interlobar plane between the middle and upper lobes An undeveloped minor fissure is more frequently found than not The middle lobe is separated from the upper lobe by a method similar to that used in removing segments Traction forceps are placed on the peripheral ends of the severed bronchus, artery, and vein (see Figure 43) The anesthetist inflates the remaining lobes for the purpose of demarcation Slight traction is made with the forceps holding the bronchovascular structures Gentle blunt dissection is made with thumb and forefinger pressing the lung substance between A small sponge forceps or wiper is also used The intercommunicating veins are delicate and the dissection must be done with a light touch The few crossing veins are readily clamped with mosquito forceps and ligated. The lobe can then be peeled away with gentle traction, after the division of interlobar connective tissue (in cases of undeveloped fissure) or fibrous bands and fused visceral pleura (postinflammatory) In the event of an incomplete major fissure of fusion resulting from disease, the same method is used as for the minor fissure, that is, the lobes are separated after the hilar structures have been divided

Right Lower Lobectomy—The components of the secondary hilum which require dissection are:

1 The superior and the basal segmental arteries, branches of the inferior pulmonary trunk
2 The inferior pulmonary vein and its tributaries
3 The superior and the basal bronchi

Interlobar Step—The pulmonary artery is accessible deep in the oblique fissure and is usually visible beneath the visceral pleura unless there are enlarged lymph nodes which fill out the crevices between the bronchi and arteries and obscure these structures. The oblique fissure is opened for its entire length if this can be accomplished easily at first Areas

of dense fusion or incomplete formation are avoided and their dissection postponed until after the bronchovascular structures have been divided The broncho arterial pedicle of the lower lobe is found deep in the fissure at the level where the minor fissure takes origin The superior artery is above and anterior to its bronchus and will be found to arise from the posterolateral aspect of the main artery directly opposite the middle lobe artery or arteries The superior artery should be dissected out peripherally in its branches before its ligation On rare occasions the posterior ascending artery to the upper lobe may be seen to originate from the superior artery and should be carefully preserved Dissection of the basal arteries is then continued The basal artery lies anterior and lateral to the basal bronchus The common stem of the basal artery is short It is well to expose the four arterial basal branches peripherally and tie them separately or in pairs (see Figure 44) Sometimes the medial and the anterior basal arteries have a common stem as do the lateral and the posterior basal arteries If so, the peripheral ties are placed on the main lobar pulmonary artery The middle lobe artery should be partially exposed before ligating the main pulmonary artery to avoid occlusion of the middle lobe artery in the proximal ligature

Proximal Step—The lower lobe is allowed to drop forward in order to expose the pulmonary ligament and the inferior pulmonary vein In wet cases it is often possible and advantageous to ligate the vein and place a preliminary occluding bronchial ligature before the lung is completely mobilized In dry cases the dissection of the vein is facilitated by a complete inferior mobilization of the lobe The posterior border of the lower lobe is retracted laterally and the posterior mediastinal pleura over the vein is incised The lower lobe veins emerge from the lobe posterior to the bronchus The basal segmental veins are found immediately above the hilar end of the pulmonary ligament A sentinel lymph node is almost always present at that level A second node is frequently found in the crotch between the superior and basal vein tributaries The branches are tied in two

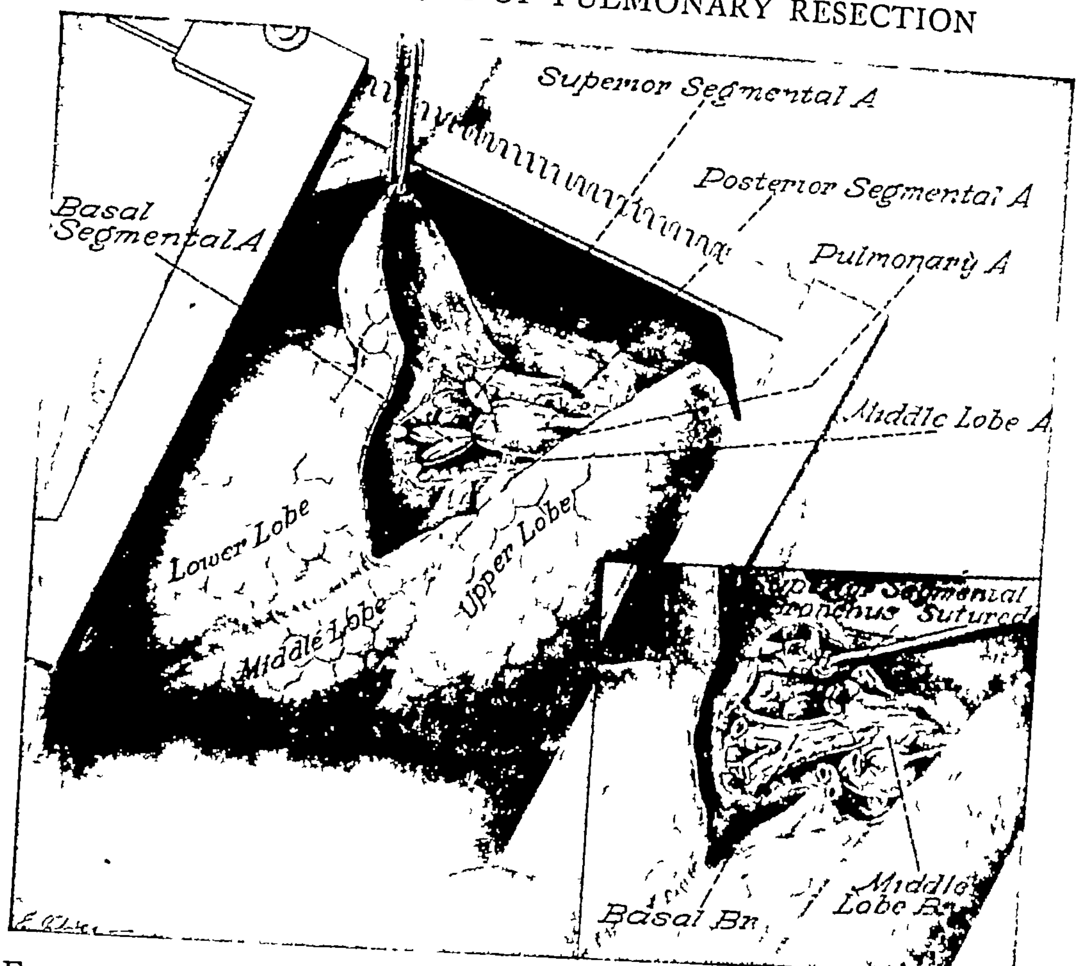


FIG 44 Drawings of a right lower lobectomy illustrating the steps in the treatment of the hilar structures In the main drawing the superior portion of the oblique fissure has been developed and the superior segment retracted posteriorly The lower lobe bronchus and the pulmonary artery and its branches are exposed The superior and basal segmental arteries have been tied separately Note the related positions of the various segmental arteries Insert shows bronchial exposure after the arteries to the lower lobe have been divided The superior segmental bronchus has also been treated and the basal bronchus is ready for division

separate groups to prevent slipping of the distal ligatures. The proximal ligature is placed on the main vein It should be remembered that the trunk of the inferior pulmonary vein is short and is contained in a pericardial reflexion

Ligation of Lobar Bronchi—Once the arteries and the veins have been ligated, the bronchi to the lower lobe can be approached, either inferiorly, posteriorly, or through the interlobar fissure The bronchial pattern resembles the

arterial distribution to the lobe and is treated in the same order as the arteries The superior segmental bronchus and the basal bronchus should be divided separately (See Figure 44, Insert) The superior bronchus arises at the same level as the middle lobe bronchus It is therefore technically dif ficult to carry the line of amputation above the origin of the superior segmental bronchus without endangering the orifice of the middle lobe bronchus

In the performance of right lower lobectomy for basal and bronchial tuberculosis a high amputation is important Re moved tuberculous lower lobes have almost invariably shown submucosal infiltration of the disease in the superior seg mental bronchus Therefore, this entire segmental bronchus should be removed Because it is on the level or above the middle lobe orifice a trans section of the intermediate bron chus is necessary Therefore, if the indication for resection is tuberculosis, the middle lobe should also be included with the excision of the lower lobe

Left Upper Lobectomy—The components of the sec ondary hilum which require dissection are

1 The upper lobe branches of the pulmonary artery, four to seven in number
2 The superior pulmonary vein and its tributaries
3 The upper (apical posterior and anterior) and the lower (lingular) bronchial divisions

Superior Step—The upper lobe is completely separated from chest wall attachments The fissure is then developed in its superior aspect. The upper lobe is retracted in an anterior and downward direction and the mediastinal pleura over the pulmonary artery is incised The apical posterior arteries are the uppermost branches of the pulmonary artery and will be easily identified by exposing the main pulmonary artery and dissecting toward the lobe They arise from the convex surface of the main trunk slightly anterior to its mid point Proximal and distal ligatures are placed on each of the branches (see Figure 45) It may be expedient to ligate the apical posterior segmental vein prior to the dis

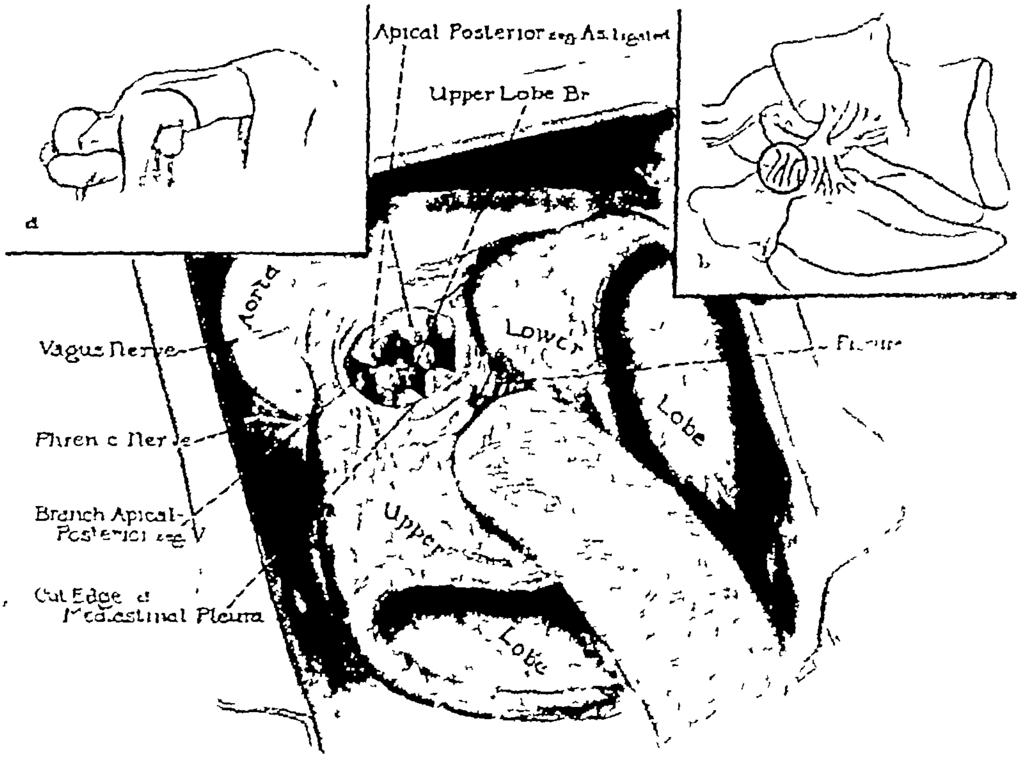


FIG 45 Drawings of a left upper lobectomy illustrating the treatment of segmental arteries Insert (*a*) shows the prone position of the patient for left thoracotomy with the incision outlined Insert (b) shows the left pulmonary artery and all its branches seen through the interlobar approach The circle includes the apical and posterior segmental arteries The main drawing shows the upper lobe held down, the visceral pleura incised, and the apical-posterior segmental arteries dissected and ligated

section of the apical-posterior arterial branches The vein is anterior to the artery which it crosses before entering into the superior aspect of the main vein

Interlobar Step—After the two arterial branches have been ligated, the main pulmonary artery is followed as it courses deep in the fissure. The remaining arterial branches for the upper lobe originate lower down on the main trunk In the chapter on anatomy the variations in number of the arterial branches to the upper lobe have been discussed With the patient in the face-down position, the upper lobe will fall forward, but it is necessary to hold up the superior division of the lower lobe to gain access to the interlobar area The remaining arteries to the upper lobe will be found

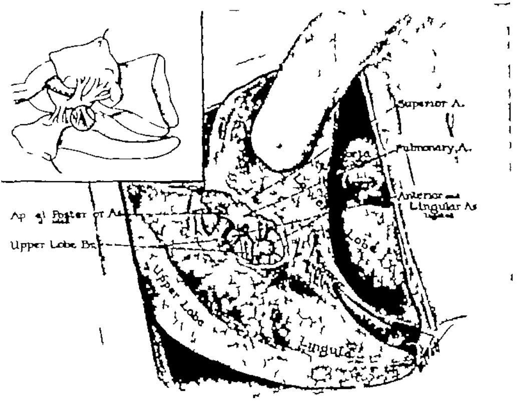


FIG 46 Drawings of a left upper lobectomy illustrating the pulmonary artery in the base of the fissure Insert shows the left pulmonary artery and all its branches seen through the interlobar approach The circle includes the anterior and lingular segmental arteries. The main drawing shows the superior division of the lower lobe held up The upper lobe has been permitted to fall forward The stumps of the apical and posterior segmental arteries are seen The anterior and lingular segmental arteries have been ligated separately Frequently these two segmental arteries originate in a common trunk.

as they originate from the lateral and anterior surface of the main trunk as they course down in an anterior direction (see Figure 46) Needless to say the main pulmonary artery as well as the artery to the superior division of the lower lobe should be carefully avoided while the arteries to the upper lobe are being dissected The course of the artery as it encircles the main bronchus, first above, then posterior, lateral, and finally anterior to the lower lobe bronchus, places it in a most vulnerable position Inflammatory changes and en

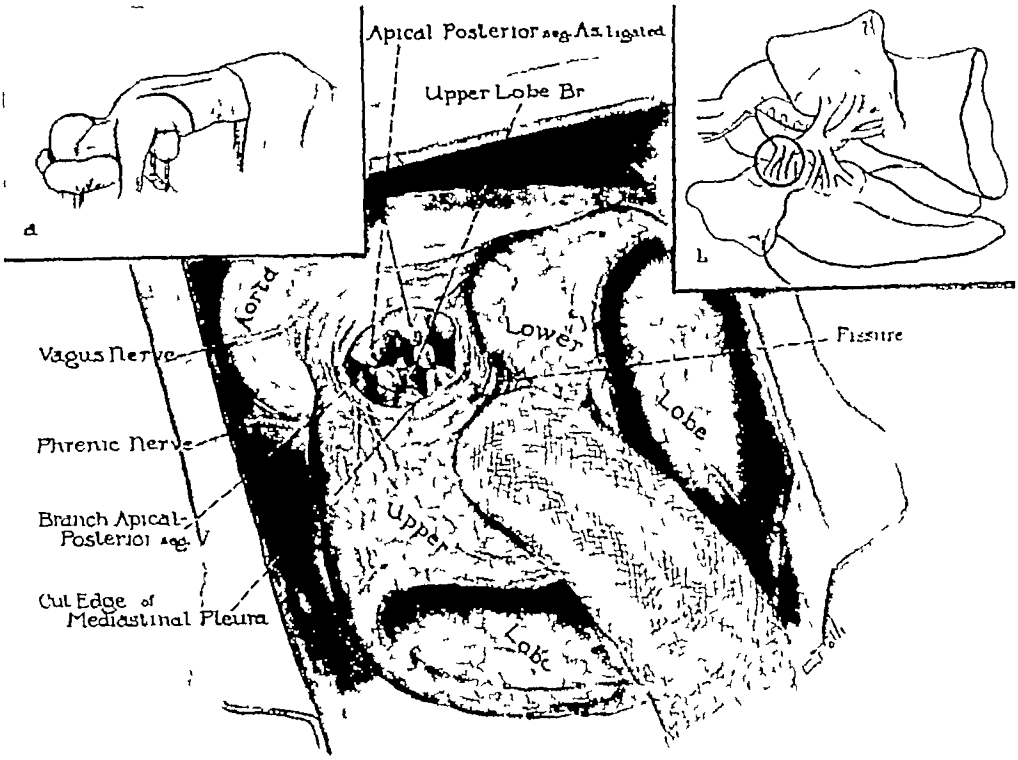


FIG 45 Drawings of a left upper lobectomy illustrating the treatment of segmental arteries Insert (a) shows the prone position of the patient for left thoracotomy with the incision outlined Insert (b) shows the left pulmonary artery and all its branches seen through the interlobar approach The circle includes the apical and posterior segmental arteries The main drawing shows the upper lobe held down, the visceral pleura incised, and the apical-posterior segmental arteries dissected and ligated

section of the apical-posterior arterial branches The vein is anterior to the artery which it crosses before entering into the superior aspect of the main vein

Interlobar Step—After the two arterial branches have been ligated, the main pulmonary artery is followed as it courses deep in the fissure The remaining arterial branches for the upper lobe originate lower down on the main trunk In the chapter on anatomy the variations in number of the arterial branches to the upper lobe have been discussed. With the patient in the face-down position, the upper lobe will fall forward, but it is necessary to hold up the superior division of the lower lobe to gain access to the interlobar area The remaining arteries to the upper lobe will be found

tracted backward and the mediastinal pleura is incised over the vein The dissection is then carried out peripherally toward the lung substance All the tributaries are isolated and ligated separately (see Figure 47) The proximal ligature may be placed on the main stem of the vein or out in the branches, whichever is most convenient, provided there is a sufficient cuff between the ligatures

Upper Lobe Bronchus—After the arteries and the veins of the lobe have been disposed of, the remaining bronchial structures are dissected They are best approached from the posterior aspect for then the surgeon always has the main pulmonary artery in full view It is preferable to amputate

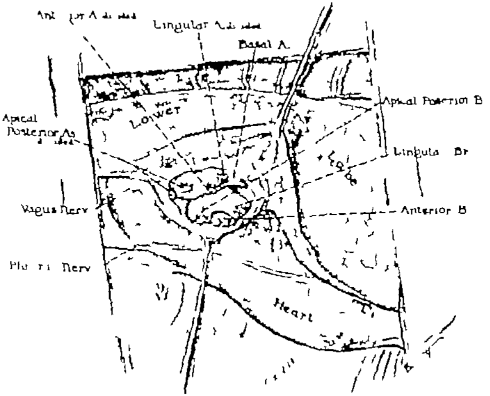


FIG. 48 Drawing of a left upper lobectomy illustrating hilar area after lobe has been removed Note related positions of stumps of ligated *segmental* arteries on the main trunk and of the three segmental bronchial stumps. *In* this instance only end sutures were placed in the segmental bronchi. The stump of the superior vein has retracted beneath the bronchial stump

larged glands may distort or obscure its position It is well at first to dissect at a safe distance out in the substance of the lung if there is any question about the location of the main pulmonary artery An injury to the main artery would constitute a grave technical error and might necessitate its ligation and the functional loss of the lower lobe If severe injury forces the sacrifice of the main artery, it is preferable to abandon lobectomy and proceed immediately with total removal of the lung

Superior Pulmonary Vein—In order to expose the vein and its tributaries, the upper lobe should be mobilized from the pericardium and the anterior chest wall The lobe is re-

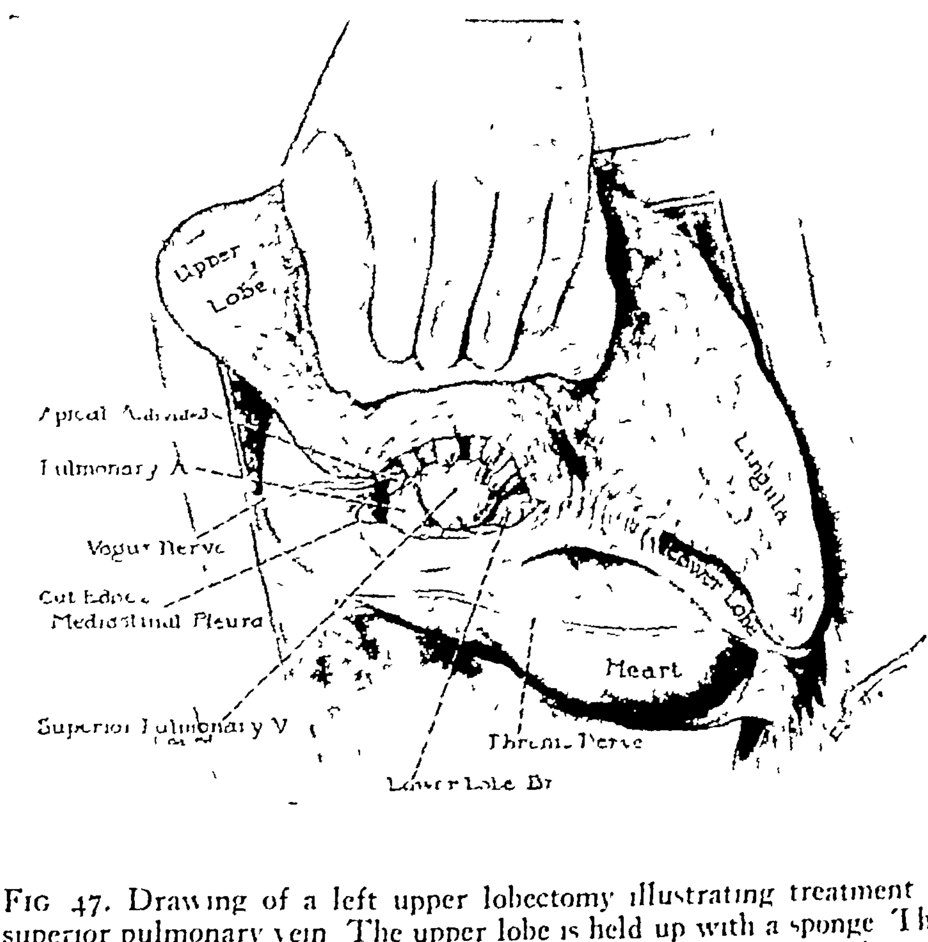


FIG 47. Drawing of a left upper lobectomy illustrating treatment of the superior pulmonary vein The upper lobe is held up with a sponge The vein has been dissected and is ready for division Distal ligatures have been placed on the tributaries Note the related positions of the pulmonary artery, the pericardium, and the phrenic nerve The stump of the apical segmental artery is shown just above the superior edge of the vein

tracted backward and the mediastinal pleura is incised over the vein The dissection is then carried out peripherally toward the lung substance All the tributaries are isolated and ligated separately (see Figure 47) The proximal ligature may be placed on the main stem of the vein or out in the branches, whichever is most convenient, provided there is a sufficient cuff between the ligatures

Upper Lobe Bronchus—After the arteries and the veins of the lobe have been disposed of, the remaining bronchial structures are dissected They are best approached from the *posterior aspect for then the surgeon always has the main* pulmonary artery in full view It is preferable to amputate

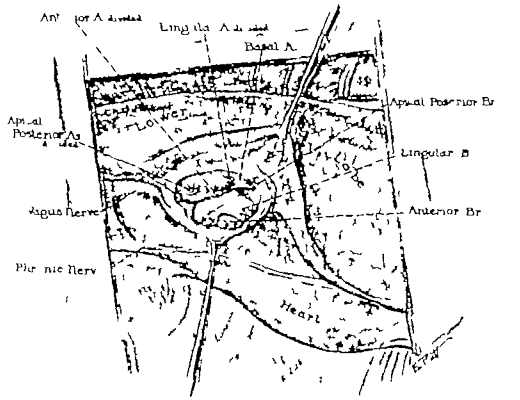


Fig. 48 Drawing of a left upper lobectomy illustrating hilar area after lobe has been removed Note related positions of stumps of ligated segmental arteries on the main trunk and of the three segmental bronchial stumps. In this instance only end sutures were placed in the segmental bronchi The stump of the superior vein has retracted beneath the bronchial stump

the bronchus at the level of the segmental bronchi (see Figure 48). If the amputation of the bronchus is carried through the lobar bronchus itself, there is a possibility that the sutures may be placed too close to the main bronchus with resulting edema and obstruction of the lower lobe bronchus

Left Lower Lobectomy—The components of the left lower secondary hilum which require dissection are

1 The superior and the basal segmental arteries, branches of the main pulmonary artery
2 The inferior pulmonary vein and its tributaries
3 The superior and the basal bronchi

Interlobar Step—All the arterial branches to the lower lobe arise from the pulmonary artery deep in the fissure Development of the mid-portion of the great fissure and the exposure of the mediastinal surface of the lower lobe constitute the first step in the dissection of the arterial branches to the lobe. The pulmonary artery is accessible deep in the fissure and unless there are inflammatory changes is visible beneath the visceral pleura Before the arteries to the lower lobe are isolated, the arteries to the lingula should be identified. It has been pointed out that the arterial branch to the superior segment of the lower lobe is the highest branch to arise from the pulmonary artery in the fissure and should be ligated separately If the common stem artery to the basal segments is long, both the proximal and distal ligatures may be placed about it It is usually safer to place individual distal ligatures on the basal branches (see Figure 49)

Posterior Step—The inferior pulmonary vein is best approached from the posterior aspect of the pulmonary hilum. The lobe is allowed to drop forward, the posterior border of the lobe is retracted laterally, and the vein is exposed The mediastinal pleura over the posterior hilum is incised It may be necessary to divide small vagal branches The lower lobe veins are seen coming from the lobe posterior to the bronchus The superior vein and the basal veins are dissected out and distal ligatures are placed around them (see Figure 50) The proximal ligatures can be placed on the main vein

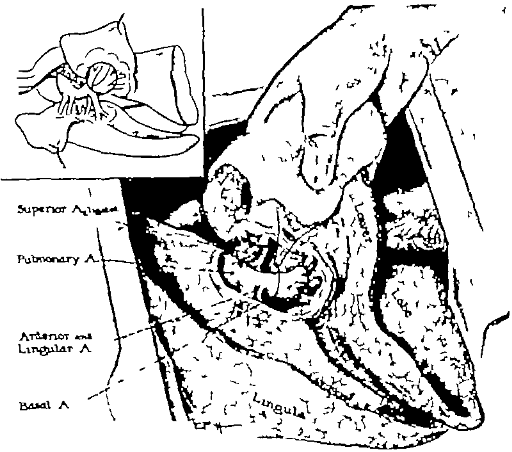


FIG. 49 Drawings of a left lower lobectomy illustrating the interlobar approach to the pulmonary artery Insert shows the left pulmonary artery and all its branches. The circle includes the superior and basal segmental arteries. In the main drawing the superior division of the lower lobe is held up to widely expose the upper portion of the interlobar area. The artery has been dissected and ligatures have been placed on the superior segmental and basal arteries. Note that the point of origin of the anterior and lingular segmental arteries is below the origin of the superior segmental artery

The diaphragmatic surface of the lung is freed and the inferior pulmonary ligament is divided In wet cases it is well to first ligate the vein and set preliminary bronchial occluding ligatures before further mobilization of the lobe In dry cases a complete mobilization of the lung may be done with safety at an early time and so expedite the hilar dissection

Ligation of Lobar Bronchus—With the arteries and the veins to the lower lobe already ligated, the bronchi to the lower lobe can be approached either from below, posteriorly

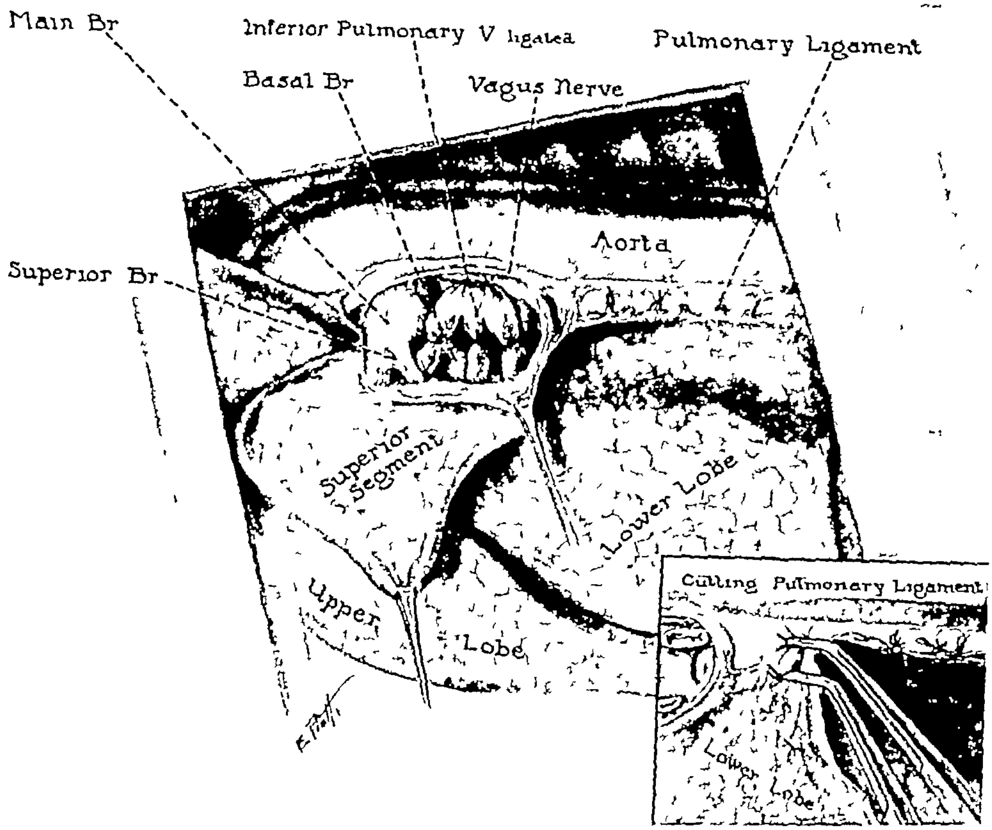


FIG 50 Drawings of a left lower lobectomy illustrating the posterior hilar area and treatment of the inferior pulmonary vein The lung has been permitted to fall forward Note that the superior segmental vein crosses the basal bronchus Insert shows division of the upper portion of the pulmonary ligament between clamps Treatment of the ligament and separation of the diaphragmatic surface of the lobe may precede the dissection of the inferior vein We prefer not to mobilize the lobe completely early in the dissection unless the bronchus has been occluded by early temporary ligation

or through the interlobar approach It is usually preferable and in many cases one is obligated to divide and ligate the superior segmental bronchus and the basal bronchus individually (see Figure 51) If the dissection and the suture line are kept down just below the superior divisional opening, there is less danger of traumatizing the upper lobe bronchus This is therefore considered the safest level Furthermore, experience has shown that the two segmental stumps heal as readily as the larger common stump and that the presence of a slightly longer pouch in bronchi of this caliber is of little consequence

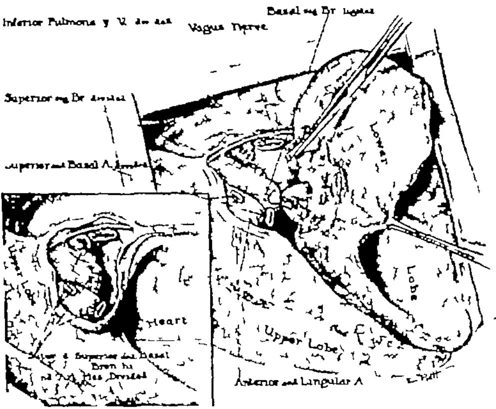


FIG. 51 Drawings of a left lower lobectomy illustrating bronchial treatment. The superior segement is reflected downward All vascular elements and the superior segmental bronchus have been divided and their stumps are shown A temporary ligature has been placed on the basal bronchus and it is ready for division Insert shows the final appearance of the hilar area after the lobe has been removed. Note that the segmental bronchi have been treated separately

In some cases it may be technically possible and in a few instances desirable to amputate the lower lobe bronchus above the origin of the superior segmental bronchus Lobectomy for adenoma or tuberculous cavitation of the lower lobe provides the most frequent indication for high bronchial amputation

SEGMENTAL RESECTION

Indications for Segmental Resection—Pathological and clinical observations have shown that certain diseases of the bronchi and lungs have a definite segmental distribution A

critical examination of complete bronchograms and detailed studies of surgical specimens bear out the fact that bronchiectasis is primarily a segmental disease and rarely involves an entire lobe. In addition, bronchiectasis tends to involve the bronchopulmonary segments in characteristic patterns The basal segments of the lower lobes are most commonly involved Churchill and Belsey have called attention to the frequency with which the lingular segment of the upper lobe is involved when the left lower lobe is diseased. They also report that "the dorsal segment (superior) of the lower lobe is found free of disease in a considerable number of cases of lower lobe bronchiectasis" As on the left side the right middle lobe, the counterpart of the lingula, is often found to be diseased concomitantly with the right basal segments A frequent bilateral pattern is that showing involvement of the right middle lobe, the lower divisions of the left upper lobe (lingula), and both right and left basal segments The superior segment of the lower lobe is rarely involved It is not only the rule to find the superior segment free of disease but also to find that this segment has undergone hypertrophy In many cases we have observed that this individual segment has larger vessels and as large a bronchus as the structures of the combined basal segments The expanded segment will frequently be found to approach a normal lower lobe in size. This finding indicates a true hypertrophy in response to changes in the basal segments early in life

In our experience approximately 85 per cent of bronchiectasis cases have multisegmental involvement, and in 30 per cent the disease is bilateral Our studies show that the lower division of the left upper lobe (lingula) is involved in about 60 per cent of those patients whose principal disease is in the left basal segments On the right side, if the right basal segments are involved, about 45 per cent of the cases will also show involvement of the middle lobe Clinical observation emphasizes the fact that good results parallel the surgeon's ability to eradicate all portions of lung that are diseased If entire lobes are considered as surgical units, serious

respiratory embarrassment will result if the disease is completely removed in bilateral cases For example, the removal of the right middle lobe, both lower lobes, and the lower division of the left upper lobe leaves the patient with one complete and one partial lobe which may not be sufficient for anything more than an invalid existence Furthermore, if bronchiectasis of the basal segments of the left lower lobe and bronchiectasis of the lingula are treated by the classic removal of the entire lower lobe and lingula, there will be only two bronchopulmonary segments remaining in the left chest to occupy the entire left hemithoracic space The marked expansion forced upon these two segments results in a pathological emphysema

Increased surgical experience in resecting pulmonary tissue has demonstrated that the bronchopulmonary segment can be employed as a surgical unit and lends itself to removal without undue technical difficulties or risk Segmental resection is now being used with greater frequency in the surgical treatment of bronchiectasis and other diseases which are confined to a bronchopulmonary segment For well localized benign disease, segmental resection is adequate and specific It not only eradicates all of the disease, but it also does away with unnecessary sacrifice of uninvolved lung tissue This approach to the excisional therapy of certain lung diseases more nearly complies with fundamental principles of surgery than if lobes or an entire lung were used as the excisional unit Furthermore, the preservation of as much functional tissue as possible becomes imperative when dealing with bilateral and multisegmental disease

Chronic abscess of the lung in some instances may be found to be localized strictly to one segment The superior segments of the lower lobes and the anterior and the posterior segments of the upper are the most frequent sites for pulmonary abscess In Chapter III, reference has already been made to the co existence of tuberculous lesions of the upper lobe with involvement of the superior segment of the lower In a few instances the remainder of the lower lobe may be entirely free of disease as evidenced by careful palpation during the

operation. Furthermore, well-circumscribed areas of tuberculous infiltration and tuberculomata involving not only part of or a whole segment are not infrequently seen.

Pulmonary cysts and miscellaneous tumors are more frequently confined to segments rather than to lobes. The former are multiple in many instances, thereby forcing consideration again for conservative excisional management. Occasionally a solitary metastatic lesion may be found in the lung upon surgical exploration. In these cases, a segmental resection is a more logical procedure than either lobectomy, pneumonectomy, or abandonment of excision. If the metastasis recurs in the ipsolateral or contralateral lung, further conservative excision is within the realm of consideration Benign tumors such as hamartoma, fibroma, chondroma, et cetera are almost always well circumscribed and confined to one bronchopulmonary segment They are frequently found in the superior division of the lower lobe

Past Limitations and Difficulties in Segmental Excision—In the past subtotal lobectomy or partial excision of pulmonary tissue has been limited more or less to one segment, the lingula of the left upper lobe in cases of bronchiectasis Churchill and Belsey have described a technique for lingulectomy and have suggested that it could apply to the excision of other segments They preserved the superior segment in two cases of bronchiectasis of the left lower lobe Lingulectomy has been performed quite generally by cutting through bronchovascular pulmonary tissue between clamps and placing either a running suture or individual ligatures in the lung substance held by the clamps. Distinct disadvantages of this practice became apparent to us and should be mentioned·

1 It is impossible to place the clamps precisely in the intersegmental plane Either too much or too little tissue is resected. Retained diseased bronchial fragments contaminate the field and invite empyema.
2 The application of clamps across the lung traumatizes the tissues A dry field is not always obtained and

hematoma formation in the remaining segment is not infrequent

3. Excessive suture material is necessary which increases foreign body reaction and predisposes to secondary infection

4. Puckering and reduction in size of remaining segments is produced Re expansion places tension on sutured lung edges and disruption of the suture level may take place

Of all the pulmonary segments the lingula is the most accessible It hangs tongue like below the remainder of the upper lobe and the intersegmental plane represents a small proportion of its surface The narrowness of the segment has invited surgeons to use clamps and sutures in its excision However, complications in all reported series have been higher than for single lower lobectomy Recently Clagett and Deterling have described a method of removing the lingula by retrograde dissection without the use of clamps They recommend the use of sutures in the inferior edges of the upper lobe, with complete pleuralization of its inferior surface We have found that in the resection of other segments the use of sutures has proved to be disadvantageous They are difficult to place without inviting air leaks and the normal shape of the remaining segment is altered and reduced in volume

A New Technique for Segmental Excision*—During the past three years, a method of segmental dissection has been developed which is fundamentally sound and universally applicable to all segments It is recognized that the segment is held within the lobe by four principal structures the bronchus the pulmonary artery, the vein, and the visceral pleura All of these structures can be identified and divided prior to the dissection of the intersegmental plane The de

* This new technique was presented for the first time in May 1946 in a brief discussion of lobectomy before the American Association for Thoracic Surgery in Detroit, Michigan. A more detailed account has appeared in Surgery Gynecology and Obstetrics 84 257-268 1947

velopment of this plane is then made possible and simplified For practical purposes, the intersegmental plane is free of intercommunicating structures Normally the bronchi and pulmonary arterial branches do not traverse the intersegmental plane Only a few venous branches cross between segments With extreme rarity small intersegmental bronchi are encountered The supporting framework of connective tissue is loose, slightly elastic, and yields to gentle blunt and sharp dissection Air leak of the raw surface is negligible and self-sealing Prompt healing of the denuded lung surface takes place since its blood supply has not been jeopardized, nor the tissue traumatized

Technique as Applied to the Resection of Any Segment —1 The segmental pulmonary artery is identified and divided In all segments except the apical-posterior (left side) and the apical and anterior (right side), the segmental artery is located and identified in the base of the major fissure as it takes origin from the main arterial trunk The horizontal fissure should be partially developed as well during the search for the artery of the anterior segment on the right side (see Figure 52)

2 The segmental vein is identified and divided (see Figure 53)

3 The segmental bronchus is identified and divided It is usually expedient to place the final sutures in the segmental bronchus at this time It has been our practice to use two or three end sutures of fine silk On rare occasions it may be necessary to place a temporary proximal mass ligature on the bronchus, remove the segment, and carry out the meticulous closure of the stump later (See Figure 54)

4 The approximate line of demarcation between segments is determined The accurate delineation of the intersegmental plane is accomplished by a) Deflation of the lobe before dividing the segmental bronchus unless the segment to be removed is already airless, b) Reinflation of the lobe by means of increased positive intratracheal pressure after the segmental bronchus has been ligated and divided The

FIG. 52 Drawings of a left basal segmental resection. The bronchopulmonary structures illustrated are shown through the interlobar exposure the main pulmonary artery (1) the anterior segmental artery (2) the superior segmental artery (3) the lingular segmental artery (4) the basal segmental artery (5) the superior segmental bronchus (B) the basal bronchus (C) The basal arteries have been dissected and other branches are seen *through the transparent pleura*. Insert shows the basal artery ligated and divided The basal bronchus and its branches are exposed The superior segmental artery is supero-anterior to the superior segmental bronchus.

The indication for segmental resection in this case was bronchiectasis and atelectasis of the basal and lingular segments. The involved segments are dark blue and contracted in appearance The superior segment is greatly hypertrophied and nearly equals in size shape, and appearance a normal lower lobe. (In all color drawings the artery is shown in red the vein in blue, and the bronchus in yellow)

FIG 53 Drawings of a left basal segmental resection illustrating the posterior hilar area. The lobe has been permitted to fall forward The pulmonary ligament has been cut. The inferior pulmonary vein (6) and its tributaries, superior (7) and basal (8) are exposed. The left main bronchus (A) and the superior (B) and basal (C) segmental bronchi are shown Insert is a close-up of the vein and the bronchi The basal vein has been carefully preserved It can be seen as it crosses the basal bronchus posteriorly

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FIG 54 Drawings of a basal segmental resection illustrating bronchial division and the initial step in the development of the intersegmental plane Insert shows the superior segmental vein (7) retracted to expose the basal bronchus (C) which has been closed with mattress sutures and is in the process of being divided Note tip of aspirator in position to remove bronchial secretion The main drawing shows the stumps of the segmental bronchus and vein A free pleural graft has been sutured to the end of the bronchus Allis forceps make gentle traction on the distal bronchus, vein, and artery The superior segment has been inflated by the anesthetist and the intersegmental line is clearly demarcated A knife is shown which is used to incise only the visceral pleura

FIG 55 Drawings of a left basal segmental resection illustrating final steps in removal of segment Insert shows hand encircling segment so that finger and thumb may be used in blunt dissection to locate the proper plane The main drawing shows intersegmental plane almost entirely developed An intersegmental vein can be seen Other small intercommunicating veins have been individually tied Bubbles indicate minor air leaks which are self-sealing The superior segment has been inflated Its relative size shows the amount of functionable lung tissue conserved

excluded segment then remains atelectatic while the adjacent segments are expanded

We have found that a reverse maneuver is occasionally very helpful while dissecting the segment At times the expanded healthy portion of lung so completely fills the thoracic wound that the work of the surgeon is hindered In cases where the diseased tissue is a relatively small proportion of the entire lung, provided the disease has not caused permanent atelectasis, it is well to obstruct the segmental bronchus after inflating the lung The healthy lung is then deflated and air is trapped in the segment to be removed In *the first maneuver one induces segmental atelectasis In the reverse procedure* the surgeon induces segmental emphysema The demarcating line between the segments can then easily be followed

5 The development of the intersegmental plane is started at the secondary hilum Forceps are applied to the ends of the severed bronchus, artery, and the vein for gentle traction (see Figure 55) Clamps are not used on the lung tissue This avoids inclusion of ramifications of the bronchi Blunt dissection is done at first Fibrous strands may be cut with scissors Bronchi strip out between the forefinger and the thumb The correct plane of cleavage is the one showing the least resistance A few branches from intersegmental veins may have to be ligated Mosquito hemostats are used If there is a question of identifying a fine bronchus or a vessel, the strand is first cut and then ligated if it bleeds If it does not bleed, it is a bronchus and should be dissected The end is picked up again and it is stripped out to its termination In the retrograde separation of a segment *small bronchi diminish in caliber fade out and detach themselves readily as they are stripped toward the intersegmental plane On the contrary the caliber of veins grows as the intersegmental plane is reached and they enter intersegmental vessels so they do not become detached with slight traction* Much of the dissection can be accomplished with the thumb and the forefinger It has been surprising to us to find the structural attachment of the segment to the remaining portion of the

lobe so frail after the few supporting structures have been released Where the separation of the segment reaches the visceral pleura this last binding structure is divided The segmental separation is then complete as well as the treatment of the raw surfaces of the remaining segment No attempt is made to fold over edges or to use grafts to cover the cut pulmonary surface (see Figure 56)

6 Reamputation and meticulous closure of the segmental bronchus is then carried out if a preliminary mass ligature was used (See technique of bronchial closure, Chapter III.)

This method enables the surgeon to restrict the extent of the resection to any bronchopulmonary segment when disease is so limited Inflammatory processes may have crossed intersegmental planes or fused structures in the tertiary hilum to

FIG 56 Drawings of the surgical exposure of a left lung illustrating its appearance before and after bi-segmental resection for bronchiectasis The drawing to the left is adapted from a color photograph of a lung of a patient affected with bilateral, multi-segmental bronchiectasis Healthy segments are inflated and are of a normal pink color Diseased segments are dark blue, contracted, and airless Note the over-development of the uninvolved segments and the relative small volume of the diseased segments The drawing to the right is adapted from a color photograph made at the conclusion of the operation The inflated healthy segments with both intersegmental surfaces are shown Note the clear-cut segmental edges and the absence of sutures The adjacent lobes have not been traumatized and their re-expansion has not been restricted by suturing of the denuded surface The large superior segment completely fills the space previously occupied by the lower lobe After closure rapid obliteration of the pleural space will take place The presence of the hypertrophied superior segment will prevent over-distention of the apical-posterior and anterior segments of the upper lobe

such an extent that dissection of a segment is impossible or unwise However, in such cases the parenchymal disease itself is usually so extensive that the lobe or entire lung must be the excisional unit if the process is to be eradicated Rarely will healthy segments have to be sacrificed for technical problems of dissection

Most frequently in the management of bronchiectasis, the

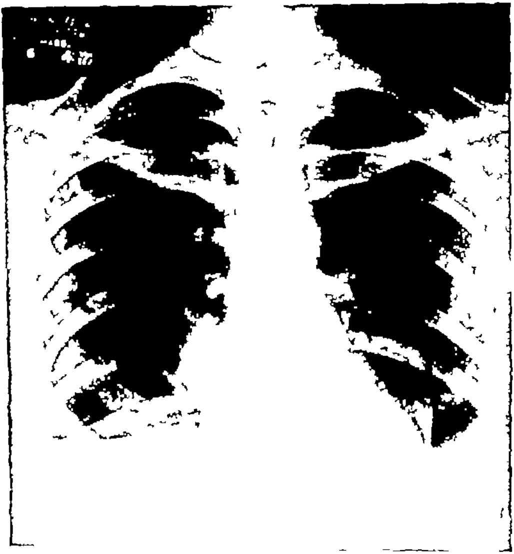

FIG. 57 Postoperative roentgenogram after bilateral multiple segmental resection for bronchiectasis The left basal and lingular segments *had been* removed six months previously The middle lobe both segments and the posterior basal segment on the right side had been removed *three months* previously Note normal appearance of lung fields, lack of evidence of emphysema, and the relatively normal position of the diaphragm on both sides.

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Technique for Specific Segments—*Basal Segmental Group, Left and Right Side*—The components of the tertiary hilum to be considered in these resections are

1 The basal arteries, branches of the pulmonary artery
2 The basal veins, tributaries to the inferior pulmonary vein
3 The basal bronchi, branches of the lower lobe bronchus

Interlobar Step—The first step is pursuit of the fissure in order to expose the interlobar portion of the pulmonary artery The basal artery is found anterior and lateral to the segmental bronchus on the left side The superior artery and the lingular artery should be exposed before the surgeon proceeds with the ligature of the basal artery and should be carefully avoided After the basal artery and its three branches have been dissected out, distal ties are placed around the branches and proximal ties over the common basal artery (see Figure 52) If the common stem of the basal artery is short, it is usually safer to dissect out the first arterial branches and place the distal ligatures around them

On the right side, the oblique fissure at the level of the origin of the minor fissure is developed Before ligature of the basal artery and its branches (four on the right) is done, the superior artery and the artery to the middle lobe should be identified

Posterior Step—The lower lobe is now allowed to drop forward, exposing the pulmonary ligament and the posterior aspect of the hilum The inferior ligament is divided between clamps, and the tributaries to the inferior pulmonary vein are exposed The tributaries to the inferior pulmonary vein emerge from the lobe posterior to the bronchi (see Figure 53) The basal segmental veins, two or three on the left and three or four on the right side, reach the inferior pulmonary vein either separately or as a common trunk or trunks The

basal group of segments will require removal together. However, only one or more basal segments may require resection, a larger proportion of the lower lobe being thereby conserved. Recently in completing treatment of a case of bilateral bronchiectasis, the resection was limited to the posterior basal segment and the middle lobe on the right side after the basal segments and lingula on the left side had previously been removed In another case the posterior and medial basal segments were removed in a well-localized chronic abscess The superior segment of the lower lobe lends itself well to individual resection, and fortunately so considering its predilection as a site for abscess For example, we elected recently to limit the resection to the superior segment of the right lower lobe for a long-standing abscess in a patient who also had bronchiectasis of the left basal and lingular segments The superior segment of the lower lobe has been removed with the upper lobe in preference to pneumonectomy in a few patients treated for tuberculosis

This method of segmental resection is also applicable to the divisions of the upper lobe For example, we have had occasion to remove the anterior segment of an upper lobe with other ipsolateral segments in treating bilateral bronchiectasis On rare instances, a segmental resection may be indicated in tuberculosis In exploring for the purpose of resecting a lobe containing a giant tuberculous cavity with fluid level, we found evidence of disease in just one segment It was then possible to limit the resection to the apical-posterior segment In another case this segment was separated to remove the apical subdivision in the treatment of a tuberculoma

The removal of a subdivision of a segment is often done. In the lower division of the upper lobe, many times, only the inferior branch of the lingula is involved and no more need be resected In middle lobe disease the resection of just one segment has been done in treating bilateral disease. In one case, for a chronic abscess, the axillary subdivisions of the anterior and posterior segments of the right upper lobe were removed with the apical portion of the superior segment of

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On the right side, the oblique fissure at the level of the origin of the minor fissure is developed Before ligature of the basal artery and its branches (four on the right) is done, the superior artery and the artery to the middle lobe should be identified

Posterior Step—The lower lobe is now allowed to drop forward, exposing the pulmonary ligament and the posterior aspect of the hilum The inferior ligament is divided between clamps, and the tributaries to the inferior pulmonary vein are exposed The tributaries to the inferior pulmonary vein emerge from the lobe posterior to the bronchi (see Figure 53) The basal segmental veins, two or three on the left and three or four on the right side, reach the inferior pulmonary vein either separately or as a common trunk or trunks The

superior segmental vein should be identified This vein is found posterior to the basal bronchus which it crosses A small tributary may enter the crotch of the main trunk and require attention before the lower trunk is dissected Distal ligatures may be placed on each individual basal segmental vein in order to widen the interval between ligatures

Ligation of the Segmental Bronchus—After the segmental arteries and veins have been ligated, the common basal segmental bronchus is approached either from below, behind, or through the interlobar fissure The bronchus should be ligated and divided so that the bronchial anchorage is disconnected before dissection of the intersegmental plane is started (see Figures 54 and 55) The method of identifying and separating the intersegmental plane has been described in detail under "Technique as Applied to the Resection of Any Segment."

Individual Basal Segments—The entire group of basal segments does not necessarily require excision together In treating bilateral bronchiectasis and other localized conditions a single segment or combinations of contiguous basal segments may be removed The general plan is the same The dissection is carried out approximately 1 centimeter farther out on the bronchovascular tree and the individual artery, vein, and bronchus identified, divided, and the segment stripped out by the retrograde method The bronchus is the key structure It may not be possible to identify either or both vascular structures before bronchial identification It is, however, almost always possible to ligate either the vein or the artery early in the dissection The bronchus can be located by palpation, then, after its distal end has been lifted out by traction and the intersegmental plane of cleavage started, the vascular structures come into view

Superior Segments, Left and Right Side—The components of the tertiary hilum to be considered in this resection are

1 The superior artery, branch of the pulmonary artery
2 The superior vein, tributary to the inferior pulmonary vein

3 The superior bronchus, branch of the lower lobe bronchus

Interlobar Step—The interlobar fissure is exposed The superior artery on the left is the first branch arising from the interlobar portion of the pulmonary artery from its posterolateral surface It arises at a slightly higher level than the lingular artery On the right side, this artery is a branch of the inferior pulmonary trunk in its interlobar portion It arises opposite the level of the middle lobe artery or arteries and below the posterior ascending branch to the upper lobe In the chapter on anatomy the fact was mentioned that on rare occasions the posterior ascending artery may originate from the superior artery Therefore, it is important to dissect for a short distance peripherally along the superior artery in order to be sure that the posterior ascending artery is not included in the ligature The superior artery on the left and right sides is slightly superior and anterior to the corresponding bronchus

Posterior Step—The lower lobe is retracted forward in order to expose the inferior pulmonary vein The superior segmental vein is the highest tributary to the inferior pulmonary vein We have mentioned before that it crosses posterior to the basal bronchus and lies inferior to the superior bronchus

Ligation of the Segmental Bronchus—The superior bronchus is slightly below the upper lobe bronchus on the left and opposite the middle on the right It is very important that sutures be placed not too close to the main bronchus on the right because they may encroach upon the middle lobe orifice

Apical Posterior Segment Left Upper Lobe—The components of the tertiary hilum to be considered in this resection are

1 The apical posterior artery, branch of the pulmonary artery
2 The apical posterior vein, tributary to the superior pulmonary vein
3 The apical posterior bronchus, branch of the upper division upper lobe bronchus

Anterior Step—The lobe is mobilized to the same extent as in the first step in a left upper lobectomy. The anterosuperior aspect of the pulmonary hilum is exposed. The apical-posterior artery arises on the convex superior surface of the main pulmonary artery as this artery begins to arch over the upper lobe bronchus This artery is superior and slightly anterior to the corresponding segmental bronchus. The

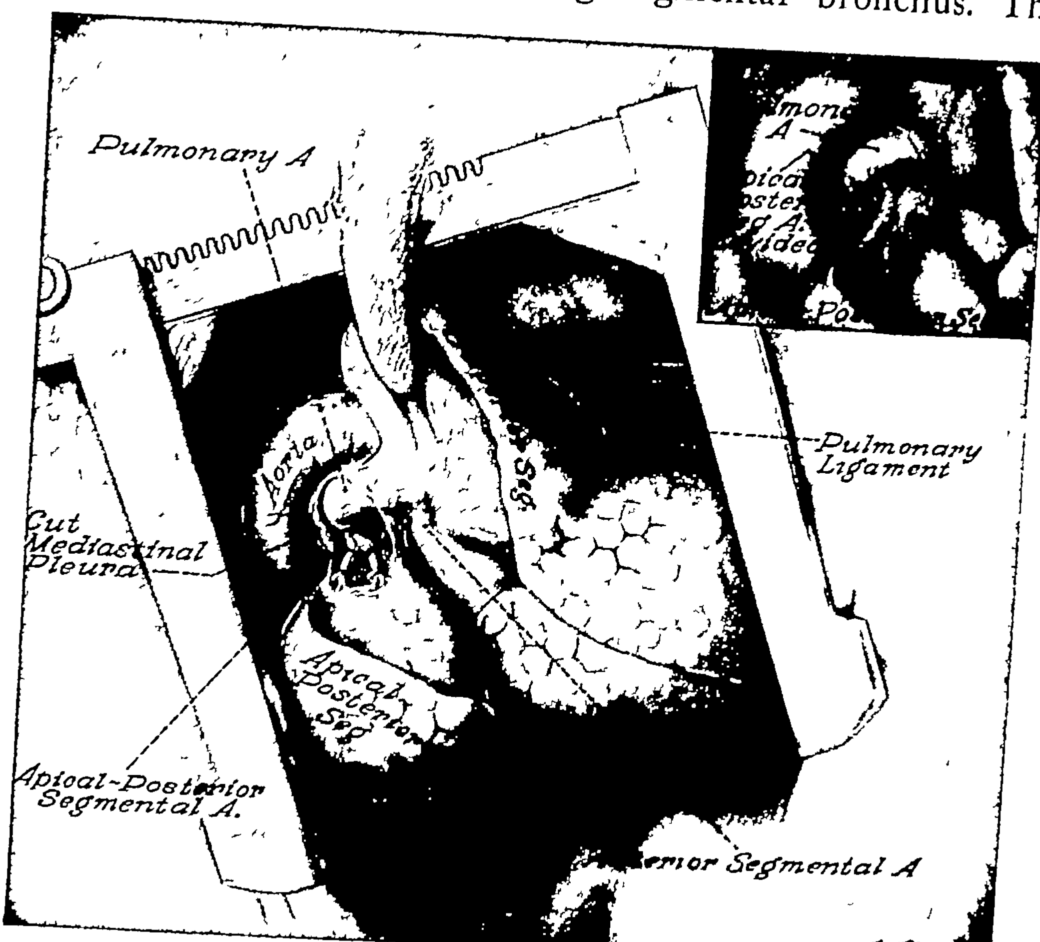


FIG 58 Drawings of the first steps in an apical-posterior segmental resection The treatment of the segmental arteries and their relationship to the segmental bronchi are illustrated The main drawing shows the apical-posterior segment mobilized, slightly rotated clockwise, and dropped downward The superior portion of the fissure has been developed and the superior segment is retracted posteriorly A portion of the main artery is exposed and the branches of the apical-posterior segmental artery have been ligated Note, lower in the fissure, the anterior segmental artery is shown as it appears under a transparent pleura The Insert shows the stumps of the ligated segmental arteries and the appearance of the hilum after dissection of the apical-posterior segmental bronchi

apical posterior artery commonly originates as a sessile trunk which divides immediately into two branches, the apical and the posterior, and therefore it is safer to peripherally dissect the artery and tie and cut the branches rather than the common trunk (see Figure 58) The apical posterior vein is ligated next This vein is inferior to the artery and anterior to the corresponding segmental bronchus (see Figure 59)

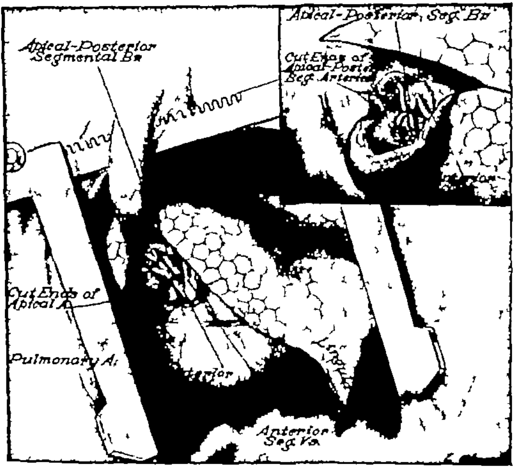


FIG. 59. Drawings of final steps in an apical-posterior segmental resection The treatment of the segmental veins and bronchi is illustrated The main drawing shows the anterior hilum with the superior pulmonary vein partially exposed The apical-posterior segmental veins have been ligated. Note the stumps of the divided apical artery Immediately behind the ligated segmental vein the segmental bronchus can be seen In the Insert the apical posterior segment has dropped forward and downward The apical posterior segmental bronchi have been ligated and are ready for division The upper and lower lobes have been inflated for the purpose of developing the line of demarcation between segments.

The apical and the posterior tributaries, before entering the superior pulmonary vein, cross the apical-posterior artery which lies behind them Therefore, it may be safer to ligate the segmental vein first and then dissect the artery After the artery and the vein have been ligated, the bronchus is dissected. This segmental bronchus is found inferior to the artery and posterior to the vein The bronchus should be divided just beyond its bifurcation (see Figure 59, Insert). It should again be emphasized that the apical-posterior bronchus most frequently arises from a common trunk with the anterior segmental bronchus, it being the uppermost of the two Therefore, if sutures are placed on the common apical-posterior stem, the orifice to the anterior bronchus may be obstructed

Anterior Segment, Left Upper Lobe—The components of the tertiary hilum to be considered in this resection are

1 The anterior artery, branch of the pulmonary artery
2 The anterior vein, tributary to the superior pulmonary vein
3 The anterior bronchus, branch of the upper division upper lobe bronchus

Interlobar Step—The interlobar portion of the pulmonary artery is exposed The anterior artery is the first branch encountered in the fissure which turns up to enter the upper lobe It has already been pointed out in the chapter on anatomy that the anterior artery may have a common origin with the lingular artery In that case the uppermost branch of the anterolingular trunk is the artery to the anterior segment It is wise therefore to dissect out on any arterial branch of a segment of an upper lobe prior to its ligation in order to avoid inclusion of a branch to a contiguous bronchopulmonary segment It bears mention that in rare instances the anterior artery may arise in the anterior hilum before the pulmonary artery crosses over and behind the upper lobe bronchus

Anterior Step—The anterior segmental vein and bronchus are reached through the anterior hilum The anterior segmental vein constitutes the middle trunk of the three tribu-

anterior segment Next, the anterior bronchus is ligated This bronchus is the lowermost branch of all the three segmental bronchi of the upper lobe Here again it should be remembered that the posterior vein is posterior to this bronchus and that sometimes this vein may emerge between the anterior and the posterior segmental bronchi

Lingula, Lower Division Left Upper Lobe—The components of the tertiary hilum which require dissection are

1 The lingular artery, branch of the pulmonary artery
2 The lingular vein or veins, tributary to the superior pulmonary vein
3 The lingular bronchus or lower division upper lobe bronchus

Interlobar Step—The interlobar portion of the pulmonary artery is exposed and the lingular artery is dissected out The interrelation of this artery to the other branches has already been mentioned several times while dealing with other segmental resections In treating bronchiectasis of the basal segments and the lingula it has been possible occasionally to place the proximal ligature on the main pulmonary artery above the origin of the lingular and the basal arteries Of course this should not be done if the lingular artery has a common trunk with the anterior artery or if the superior artery does not take origin at a sufficiently high level (see Figure 60)

Anterior Step—The upper lobe is retracted backward The anterior hilum is exposed The superior pulmonary vein is identified and the lingular vein or veins are dissected The lingular vein is the lowermost tributary to the superior pulmonary vein and lies anterior and slightly inferior to the lingular bronchus (see Figure 61) While performing either a basal or lingular segmental resection, the surgeon should keep in mind the possibility of a lingular vein tributary to the inferior pulmonary vein This vein joins the inferior pulmonary vein anteriorly as a common trunk with the anterior basal segmental vein The intersegmental vein crosses the fissure anterior to the basal bronchus On one occasion we found concomitant with this anomaly a small bronchial

arterial supply to the anterior segment is through the anterior artery which is a branch of the superior pulmonary trunk. However, this segment may also receive small branches from the apical artery and on very rare occasions the anterior segment is supplied by branches arising in the interlobar portion of the artery either from the main artery or the middle lobe artery. The venous return of the anterior segment is also irregular. There are two superficial veins, the anterior vein, which is a branch of the anterior-apical vein, and the inferior vein. There are also intersegmental veins draining into the posterior vein. Another important practical consideration is that during the final dissection of this segment three intersegmental planes require development. Two of these are formed by the opposing surfaces of the other two segments of the right upper lobe and the third by the upper surface of the middle lobe. Although the minor fissure theoretically separates the under surface of the anterior segment, this fissure is frequently fused and is traversed by intersegmental veins.

Anterior Step—The upper lobe is retracted backward to expose the anterior hilum of the lung. The superior pulmonary vein and all its tributaries are dissected. The anterior vein is ligated. Posterior to the anterior vein is the anterior artery which is next ligated. Posterior to the artery is the posterior vein, and this should be carefully avoided. It should be remembered that the posterior vein lies posterior to all arteries and bronchi of the upper lobe but may sometimes emerge from the upper lobe between the anterior and posterior bronchi. The next structure to be ligated is the inferior vein. This vein runs along the inferior margin of the upper lobe bordering the minor or horizontal fissure, and, it is, at the hilum, the lowermost tributary from the upper lobe to the superior pulmonary vein.

Interlobar Step—After the anterior vein, the anterior artery, and the inferior vein have been ligated, the horizontal fissure is developed and the interlobar portion of the pulmonary artery is exposed in order to ascertain whether or not there are anterior ascending arteries running toward the

After the lingular vein has been tied, the lingular bronchus is ligated (see Figures 62 and 63) It should be re-emphasized that the anterior bronchus and the lingular bronchus may have the same origin Then it is wise to place the bronchial sutures on the segmental lingular bronchi Otherwise, the common lingular stem bronchus is long enough to be

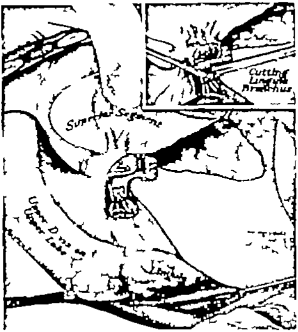


FIG. 62 Drawings of a lingulectomy illustrating the interlobar area and treatment of the lingular bronchus Proximal mattress sutures have been placed in the common stem and distal ligatures in the branches. Note again the appearance of the diseased segment and the rudimentary fissure Insert is a close up view showing the actual division of the bronchus Note close position of the tip of the aspirator

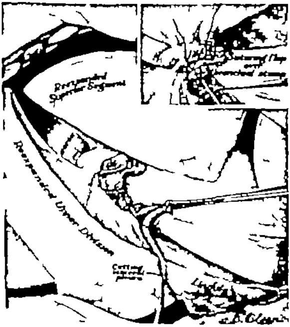


FIG. 63 Drawings of a lingulectomy illustrating final steps in separation of segment. Insert shows placement of sutures through end of lingular segmental bronchus anchoring a free pleural graft Note relative positions of basal and lingular bronchial stumps to their corresponding arteries. The main drawing shows initial step in development of intersegmental plane. The healthy segments have been expanded and the line of demarcation is evident The separation of the intersegmental plane is done as is that of a basal segment

FIG 60 Drawings of a lingulectomy illustrating the interlobar region after resection of basal segments has been accomplished The segmental arteries of the lingula (4) have been ligated distally A thread is shown indicating the position of the proximal ligature Note the position of the superior segmental artery (3) and the corresponding bronchus (B) The anterior segmental artery (2) can be seen through the transparent visceral pleura The lingular segment appears contracted and airless Note the rudimentary intersegmental fissure Insert is a close-up view of the interlobar region showing the lingular artery divided and the posterior aspect of the lingular bronchus (D)

branch arising from the inferior aspect of the inferior lingular segmental bronchus which crossed the fissure line and entered the lower lobe at the level of the anterior basal bronchopulmonary segment

FIG 61 Drawings of a lingulectomy illustrating the treatment of the vein in the anterior hilum The upper lobe has been lifted up to expose the superior pulmonary vein (9) The upper edge of the pulmonary artery (1) is within view The lingular vein (10) has been dissected and ligated Insert is a close-up view of the divided lingular vein (10) The anterior aspect of the lingular bronchus (D) can be seen

After the lingular vein has been tied, the lingular bronchus is ligated (see Figures 62 and 63) It should be re empha sized that the anterior bronchus and the lingular bronchus may have the same origin Then it is wise to place the bron chial sutures on the segmental lingular bronchi Otherwise, the common lingular stem bronchus is long enough to be

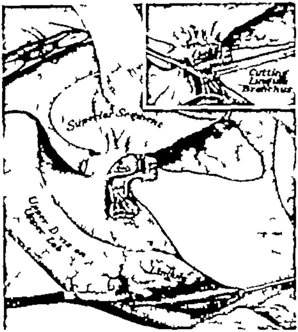


FIG. 62 Drawings of a lin gulectomy illustrating the in terlobar area and treatment of the lingular bronchus. Proximal mattress sutures have been placed in the common stem and distal ligatures in the branches. Note again the appearance of the diseased segment and the rudimentary fissure. Insert is a close up view showing the actual divi sion of the bronchus Note close position of the tip of the aspirator

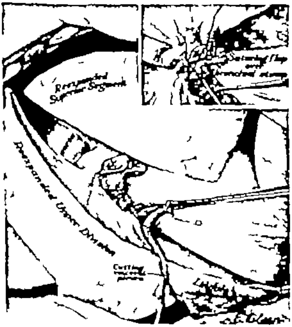


FIG 63 Drawings of a lingu lectomy illustrating final steps in separation of segment. In sert shows placement of su tures through end of lingular segmental bronchus anchor ing a free pleural graft. Note relative positions of basal and lingular bronchial stumps to their corresponding arteries. The main drawing shows ini tial step in development of intersegmental plane. The healthy segments have been expanded and the line of de- marcation is evident The separation of the interseg mental plane is done as is that of a basal segment

amputated at its trunk and sutured at this level without encroaching upon the remainder of the upper lobe bronchus

Inferior Lingular Segment and Medial Middle Lobe Segment—In bronchiectasis cases frequently only the inferior lingular segment and medial middle lobe segment are the ones involved in conjunction with the basal segments of both lower lobes Following the same surgical principle as for any other complete segmental division, these two segments can be removed Often the inferior lingular segment is partially divorced from the rest of the upper lobe by a notch or rudimentary fissure In our experience if the lingula is involved, the disease is more frequently found in just the inferior segment than in both lingular segments When the disease is so limited the inferior segment can be more easily removed than the two lingular segments together On the right side the middle lobe cannot so readily be divided in the event of subtotal involvement The amount of lung tissue conserved is so small that the removal of an individual segment in the middle lobe is not often feasible However, in the event of an undeveloped minor fissure and a healthy lateral segment of the middle lobe it may be technically easier to remove just the diseased medial segment than to take the entire middle lobe.

CHAPTER VI

Post Resection Management and Complications

GENERAL CARE

IN THE general care of patients following pulmonary resections, the same measures should be taken that have been found to be of value after any major surgical procedure. Fluids and nourishment are given immediately. Post operative low hemoglobin content and serum protein levels are restored to normal by means of transfusions and plasma. Oxygen therapy is not routinely necessary but is important for the first few hours of adjustment after operation in some cases and particularly in older patients. Following lobectomy or segmental resection an oxygen tent or a nasal catheter is rarely indicated. In fact, deep breathing should be encouraged and is more apt to occur if the patients are in a normal atmosphere.

The three primary concerns following pulmonary resections are 1) the maintenance of an unobstructed airway, 2) the complete re expansion of the remaining lung tissue after lobectomy and segmental resections with obliteration of the pleural space, and 3) the prevention of sudden or excessive mediastinal shift in either direction after total resection.

Patent Airways—Accumulation of secretions in the tracheobronchial tree complicates the convalescence because it interferes with ventilation, predisposes to pulmonary atelectasis and infection, and impairs re expansion of lung tissue. The problem of elimination of bronchial secretions is greatly simplified if the patient starts his convalescence with free airways. The prone position and maintenance of the cough

reflex during operation has done much to minimize postoperative difficulties. Also, a patient who is alert, cooperative, and able to cough immediately after operation will usually keep the airways open himself. However, the formation of variable amounts of bronchial secretion is a continuous process and is therefore an inescapable problem during the first few days of the convalescence. The following measures have aided in maintaining an effective cough and in keeping the airways clear.

Minimizing Pain—Great care in the avoidance of the intercostal nerves, in the placement of subperiosteal pericostal sutures, and in the creation of a stable thoracic wall does much to minimize pain. With a stable chest wall the act of coughing is more effective. Patients require fewer and smaller narcotic injections. Mild sedation for pain is used, but not enough to depress the cough reflex. At first, the patient is placed on the operated side which limits thoracic movement on that side. The patient is turned from side to side at least every hour. The nurse gives manual support to the chest wall during periods of coughing as this permits effective coughing with less discomfort.

Liquefying Secretions—Thick, tenacious bronchial secretions will produce harassing coughing spells which may lead to exhaustion of the patient. Steam inhalations of compound tincture of benzoine at regular intervals and the use of expectorants such as ammonium chloride and terpin hydrate may aid the patient in dislodging and raising secretions.

Tracheal Aspiration—If the previous simple measures have proved to be ineffective, intratracheal aspiration after insertion of a catheter through the nose, larynx, and trachea is carried out. The nurse or doctor stands at the head end of the bed. A soft rubber catheter of moderate size is used. A small opening for an air vent is cut near its larger end. The patient's head is slightly extended, with the mouth open and tongue out, and the catheter is threaded into a nostril. When its tip reaches the posterior nasopharynx, the patient is asked to cough. At this instant, the catheter is given a quick thrust and, in most instances, will find its way into the trachea

Several trials may be necessary The catheter is then connected to a fairly strong suction system The opening in the catheter permits the operator to open and close the suction at short intervals A suction force strong enough to withdraw heavy tenacious mucus will draw and fix the tube to the side of trachea or bronchus unless the suction is momentarily interrupted Rotation of the head to the right favors passage of the catheter into the left bronchus and vice versa This procedure is a most valuable maneuver for it is almost as effective as bronchoscopic aspiration and it can be done by the nurse in the ward

Bronchoscopic Aspiration—Occasionally it is necessary to resort to bronchoscopy in order to aspirate bronchial secretions If other measures fail, the need for bronchoscopic aspiration should be recognized early in order to prevent atelectasis

The Pleural Space—In pneumonectomy cases, accumulation of fluid and blood in the pleural space may lead to increased pressure with displacement of the mediastinum toward the sound side The patient may complain of tightness in the chest and shortness of breath The temperature may rise and pulse become rapid By percussion and auscultation the position of the heart can usually be determined The position of the trachea can be ascertained by palpation if markedly displaced Fluoroscopy or bedside x ray is the most exact method of checking mediastinal position Pressures may be adjusted by needle aspiration of variable amounts of fluid or air until normal negative readings are obtained The average patient requires one or two such aspirations during the post operative period A highly negative pressure may develop because of the escape of air or fluid into the subcapsular space or soft tissues of the chest wall This is most likely to occur in those complicated cases where the integrity of the thoracic cage was difficult to reestablish and its air tight closure not a particularly firm one The injection of air to establish a normal negative pressure may then be necessary

In lobectomy and segmental resection cases, the rapid obliteration of the pleural space eliminates the development of fibrothorax and minimizes the chances of pleural infection This is important for then the return of maximum function is ensured All lobectomy and segmental lobectomy cases are drained with one or two rubber catheters (size 24) which are connected with gentle suction (see Figure 64) The catheters are withdrawn when full re-expansion has been obtained and after the period of fluid formation has passed This need for drainage varies from 24 to 72 hours with most tubes being withdrawn during the second postoperative day. If the catheter becomes plugged or re-expansion of the lung is not even, loculated air or fluid-containing pockets remain in the pleural cavity after the drainage tube has been removed Fluoroscopic examinations will aid in following the progress of re-expansion and will also help in localizing air or fluid collections Serum or blood should not be permitted to remain long in the pleural cavity They prevent re-expansion, increase the danger of infection, and produce thickening of the pleura

Currently our plan for the prophylactic intrapleural use of antibiotic agents is as follows In uncomplicated or non-grossly contaminated cases, a solution containing 200,000 units of penicillin and one gram of streptomycin is injected into the pleural cavity at the conclusion of the operation An intrapleural injection of the same amount of penicillin is given on the second and fourth postoperative days. In pneumonectomy cases, the drug is given at the time the intrapleural pressure is checked In cases of lobectomy or segmental resection, the injection is made through the drainage tube as long as the tube is in place Immediately following the injection, the tube is clamped for a period of six hours In grossly contaminated cases, the intrapleural injection of one or both drugs, depending upon the culture, is given daily for a period of seven days or more If there is a systemic reaction to an infection of the pleura or evidence of an infection elsewhere, the antibiotic drug is also given intramuscularly If purulent sputum continues to be raised post-

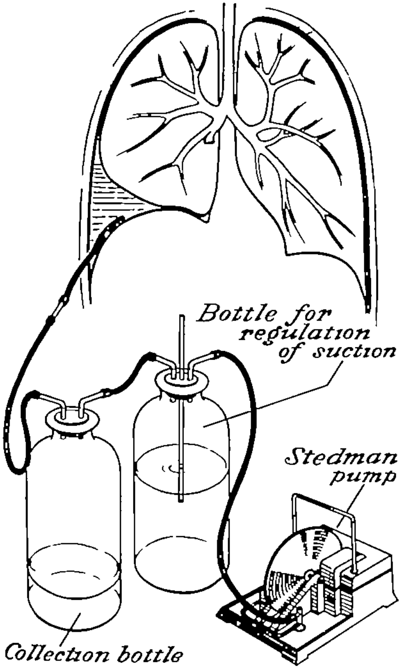


FIG. 64. Diagram of arrangement of drainage bottle and suction apparatus. Wall suction a magneto type pump or a water suction system may be used The degree of negative pressure to be maintained in the system is controlled by an open glass tube one of which is under water in the closed regulating bottle. The suction is broken if the negative pressure exceeds in centimeters of water pressure the depth of submersion of the glass tube.

operatively, inhalation therapy is re-instituted This necessity arises most frequently in cases of bilateral bronchiectasis following the operation on the first side

Following uncomplicated resections for tuberculosis, the intrapleural injection of one gram of streptomycin is given every other day for a period of ten days In the presence of gross contamination, the drug may be given intrapleurally for longer periods It is also our current practice to give streptomycin intramuscularly for a limited course in cases showing contralateral disease of questionable stability Grains one and one-half are given daily in divided doses for two days preceding and twelve days following the operation

The patient is helped out of bed as soon as possible—sometimes on the second or third postoperative day This increases pulmonary ventilation and further aids in re-expansion Moreover, the patient's morale, appetite, and muscle tone improve, and the convalescent period is shortened

COMPLICATIONS

Modern surgical technique, with individual ligation of hilar structures and a type of closure of the bronchus more conducive to permanent healing, has greatly decreased the incidence of postoperative infection of the pleural space Chemotherapeutic agents have also proved to be of value Pleural infection, although infrequent, represents a serious complication of pulmonary resection

Most frequently, pleural infection can be traced to the following factors, the last being by far the most important and serious

1 Spilling of purulent material during the operation
2 The presence of pre-existing chest wall infection, of empyema, or of a draining sinus
3. Bronchial leak

The method used in dissection of the lung, and the care necessary to avoid soiling of the pleural space and contamination from the cut bronchus have been mentioned elsewhere

The presence of a draining sinus at the time of operation may force the surgeon to enter an infected area at some time during the resection in order to liberate the lung Contamination of the pleural space may occur at that particular step

Bronchial Fistula—Fortunately, modern methods of dissecting, ligating, and covering the bronchial stump have greatly reduced the incidence of fistula formation In uncomplicated resections the bronchus heals without leak in almost every case When the treated bronchus has previously been involved in disease or when there has been gross contamination of the operative field, the possibility of failure to obtain primary healing must be kept in mind The incidence of bronchial leak has been reduced to under 5 per cent

Bronchial leak, when present, usually appears in or after the second postoperative week The patient may complain of tightness and shortness of breath Coughing spells and blood tinged sputum are sometimes warning symptoms The patient may suddenly cough up a large amount of serosanguineous fluid Fluoroscopic examination may reveal a fluid level where previously there was nothing but diffuse density In pneumonectomy cases, the presence of air in the chest six or more weeks after operation should make one suspect the presence of a bronchial fistula Manometric readings may disclose air leaks The failure of the space to hold consistently to negative pressure readings after air aspiration is positive evidence

Once the bronchial fistula has been diagnosed, attempts are made to remove all the fluid from the chest and the patient is kept constantly on the operated side to avoid aspiration of secretions into the bronchial system

In tuberculous patients, a bronchial fistula is a most serious complication Unless it is promptly closed the formation of a tuberculous empyema is a certainty and the flooding of secretions in the contralateral or ipsolateral lung will lead to tuberculous spread

Prompt action is necessary if a bronchopleural fistula de

velops The program of management of this complication after resection has been as follows·

Pneumonectomy Cases—In pneumonectomy cases, the pleural space is usually infected by the time the fistula is discovered In that event, drainage without an attempt to resuture the bronchus is the most that can be done This can be accomplished by intercostal trocar and catheter drainage if early or by rib resection if late Chemotherapy usually delays the appearance of all complications relative to the element of infection so most cases can best be managed by rib resection and open drainage

The patient is operated upon under local anesthesia, in the face-down position and turned so that the affected side is in a dependent position This minimizes the possibility of contralateral bronchial flooding Dependent drainage is essential and can best be provided by resecting a three-inch segment of the eleventh rib from transverse process forward and developing the costophrenic sinus at its lowermost point The diaphragm is depressed and the pleural space opened from a point beneath the tenth rib In this way the bottom of the pleural space is opened, not its side All fluid is aspirated and clots of fibrin or blood are removed The low drainage site makes it difficult to locate the fistula and it is usually not wise to attempt to close it by suture in such emergencies. The pleural cavity is packed with a sufficient number of gauze strips to fill the thoracic wall opening The wrist portion of a rubber glove is placed around that part of the gauze which comes in contact with the soft tissues of the chest wall

The healing of the bronchus and the obliteration of the pleural space represent a serious problem which requires a series of subsequent operations Bronchoscopic cauterizations of the stump are carried out at intervals of two to three weeks. A bead of sodium hydroxide which has been fused on a bronchoscopic sponge carrier is used The bead is applied to the stump for 10 to 15 seconds and the area then neutralized with 6-per-cent acetic acid Five or six cauterizations may be necessary Simultaneously with this treatment and as soon as the patient's condition allows it, a complete

paravertebral thoracoplasty is carried out in stages The first stage, which may usually be performed one or two weeks after the pleural drainage, consists of the removal of the posterior two-thirds of the seventh to tenth ribs The second stage is done ten days later when the anterior half of the second to fifth ribs, including the cartilages of the second, third, and fourth ribs and a section of the fifth rib are removed The third stage is performed two weeks later when posterior halves of the second to the fifth ribs are removed We have not found it necessary to remove transverse processes With this regime, we have succeeded in obliterating the pleural space in a few months The patient may have to wear a small rubber tube in the pleural space to afford drainage The tube is diminished in size and length at intervals until complete healing is obtained

It has been found that the first rib does not need to be resected in most instances, even in the presence of an empyema The periosteum of the under surface of the rib is separated This permits the chest wall to immediately drop in as far as if the rib were removed The contracting processes hold the chest wall to its new position There is a great advantage in conserving the top rib The upper thoracic arch is maintained and cervical scoliosis is prevented

Early in our experience the routine above down sequence of rib removal that is used in the therapy of tuberculosis was used to obliterate the pleural space after resection Occasionally, infection *of the subscapular space occurred after the* first posterior or upper stage This could not be avoided for the chest wall itself had become infected from within The removal of further lengths of the fifth rib, which is divided posteriorly, at the time of the pneumonectomy would often open up an area of infection which had penetrated the chest wall posteriorly The resection of the upper ribs at the first stage created a large subscapular space with a concave inferior surface and a convex and mobile superior surface Infections of this space delayed completion of the thoracoplasty A reversal to the below up sequence has obviated this hazard The chest wall is dropped down with the scapula

and at no time is a space between the scapula and chest wall created

Lobectomy Cases—When a fistula has developed following lobectomy or segmental resection it has, in some cases, been possible to carry out exploratory thoracotomy early If the diagnosis can be made before infection develops, it is possible to close the fistula transpleurally The patient is placed in the prone position, and the operation is carried out under local anesthesia with intratracheal intubation The previous scar is resected and the pleural space is entered through the same intercostal space used for the resection The lobar hilum is inspected Sometimes, one or two pinpoint openings in the bronchus can be seen It is sometimes necessary to administer positive pressure in order to detect the bronchial leak Then either a hiss can be heard or air bubbles can be demonstrated if saline is poured over the area The bronchial leak is repaired by means of two or three interrupted stainless steel sutures (size 34) which are placed either through the bronchus or in the peribronchial tissue, and tied around a piece of free muscle applied directly over the bronchial leak The bronchus is then tested for air tightness by increasing the pressure in the bronchial system, and by filling the pleural cavity with saline Further sutures may sometimes be needed The lung may be found to be covered with an organized fibrinous layer which will interfere with subsequent re-expansion In these cases, a decortication of the remaining lobe or segments is carried out

A selective upper thoracoplasty may be performed at the same time as the closure of the bronchial fistula if this complication has developed following upper lobectomy for tuberculosis The second to the fifth or sixth ribs are removed The first rib is left in place The transverse processes are not disturbed. Such a limited thoracoplasty will aid in closing the pleural space The pleural space is drained with a rubber catheter (size 24) which is attached to a negative suction apparatus No attempt is made to suture the pleural or intercostal muscle edges as rapid absorption or escape of air from the space is desirable

For the few complications of this sort encountered, we have always been successful in closing the bronchial fistula, obtaining re expansion of the remaining lung, and obliterating the pleural space It is unwise to wait until the pleural infection sets in, for then primary resuture of the bronchus is difficult and hazardous

Empyema—Post pneumonectomy empyema has occurred in slightly under 10 per cent of the cases in our experience The diagnosis was based on the direct examination of the pleural fluid The continued formation of fluid requiring repeated chest aspirations suggests infection of the pleural space, even if the fluid is clear and bacteria are not seen on direct smear Culture of the removed specimen has usually revealed bacterial growth

Treatment varies depending upon whether a bronchial fistula is or is not present In the event of a bronchial fistula, the treatment of a complicating empyema is the same as that outlined for the fistula itself

Empyema without Fistula—If the fluid removed is thin, showing antibiotic bacteria, the space is treated by repeated needle aspirations and daily intrapleural injection of penicillin (50,000 to 100,000 units) or streptomycin (1 gram), or both dissolved in 20 cc of distilled water It is important to remove as completely as possible all the pleural fluid prior to the instillation of the antibiotic drug The pleural space is very often loculated, and all the separate empyema pockets should be reached by selecting multiple sites for insertion of the needle It has been possible in our experience to sterilize approximately 25 per cent of the spaces that become infected Usually after the third or fourth intrapleural injection of the antibiotic, the cultured fluid will show no growth, or very little growth The intrapleural use of penicillin or streptomycin is supplemented by intramuscular injections of the drugs

If, however, the pleural fluid shows a tendency to become cloudy, turbid, or thick, and the general condition of the patient suggests sepsis, a negative fluid culture should not

cause one to delay surgical drainage Early in our experience with the sulfa drugs and penicillin we were led into a false sense of security by repeated negative culture reports and we deferred drainage, thus greatly prolonging the total recovery period

Drainage—In the event that drainage becomes necessary, rib resection and open drainage has been chosen as the most suitable method The operation is performed under local anesthesia, with the patient in the prone or side position The eleventh or occasionally the tenth rib is resected from the transverse process forward three or four inches This selection of rib level is made to ensure the most dependent drainage Even with a highly-placed diaphragm it is preferable to create the opening in the thoracic cage at a low level The diaphragm may if necessary be separated from the ribs above the drainage site The corresponding intercostal nerve and the one above are crushed to anesthetize the wound area and thus minimize pain or discomfort during subsequent dressings The endothoracic fascia is sutured to the superficial fascia to obliterate tissue planes and prevent dissecting infections The pleural space is thoroughly cleansed, all debris is removed, and the space is washed out with saline. The most appropriate sulfa compound (5 to 10 grams) is then spread in the space The pleural cavity is packed with plain gauze strips The wrist of a rubber glove provides a very satisfactory encircling protective covering for the gauze at its point of contact with soft tissues of the chest wall The packing is not disturbed for 4 to 6 days. The outer dressing is changed as frequently as necessary Then the intrapleural gauze strips are changed every 24 to 48 hours

Post-pneumonectomy empyema in children treated by drainage has not required subsequent thoracoplasty for space obliteration Gradually the chest wall contracts, the diaphragm becomes elevated and the mediastinum moves over, and thickening of the parietal and mediastinal pleural layers accomplishes complete closure The healing process may extend for a period of weeks or months In subjects who have not reached full growth it seems highly desirable to avoid

thoracoplasty regardless of the duration of the convalescent period

In adults the necessity of thoracoplasty for space obliteration in empyema following pneumonectomy should be recognized early There are only two conditions which need alter the decision for operation First, patients in whom a palliative resection for malignancy has been performed do not have a life expectancy of sufficient length to justify further surgery Second, certain patients in extremely poor condition may have other complicating factors which decide the issue In all other adult patients who develop this complication a thoracoplasty should be undertaken without long delay Prolonged drainage from a large internal surface results in excessive protein loss Chronicity also leads to excessive stiffening of the chest wall tissues and obliteration of the cavity becomes more difficult In most cases it is feasible to proceed with the thoracoplasty within the two week period following rib resection The same general plan for stage sequence and extent of rib removal is carried out as has previously been described under management of bronchial fistula There is one exception that warrants comment In patients who develop a delayed empyema of low virulence and who are in reasonably good general condition it is advantageous to combine the low thoracoplasty stage with the drainage operation The seventh, eighth, and ninth ribs are removed by carrying the incision through the lower half of the scar of the pneumonectomy This wound is closed and the tenth rib is removed through a small low incision and the space drained The removal of the upper ribs is then completed in two stages, first the anterolateral and then the posterior resection

In recent years, empyemas following lobectomy have been reduced to an incidence of under 3 per cent The treatment of post lobectomy empyema with fistula has been outlined in the discussion of treatment of the fistula itself Empyema without fistula is first treated conservatively with needle aspiration and intrapleural injection of penicillin and/or streptomycin if the pleural fluid is thin and the culture shows

bacteria that are sensitive to the antibiotics In these cases, it has been possible to sterilize the space in almost all the patients treated When infection becomes controlled, the lung re-expands and the pleural space obliterates. If conservative treatment fails and the fluid becomes definitely purulent, open drainage is provided An empyema following upper lobectomy is drained in the mid-axillary line with resection at the fourth or fifth level The empyema space after lower lobectomy is drained by resection of the eleventh or tenth rib posteriorly Thoracoplasty following empyema drainage in lobectomy cases is seldom necessary. The re-expansion of the remaining lung and retraction of the chest wall and diaphragm will aid in promoting space closure The use of segments as excisional units in bronchiectasis and other benign conditions has done much to simplify space obliteration following subtotal resection of lung tissue

Intrapulmonary Infection—Infection of the lung following pulmonary resection has become a rare complication Prophylactic measures such as pre-operative postural drainage, bronchoscopic aspiration, antibiotic inhalation therapy, careful aspiration of bronchial secretions during operation, early temporary ligature of the bronchus, and all of the post-operative measures to keep the airways open have greatly reduced the incidence of post-operative atelectasis which, in the past, was largely responsible for intrapulmonary complications

The fear of a contralateral flare-up of pneumonitis or pneumonia in bilateral bronchiectasis has been largely eliminated The post-operative course in patients with bilateral bronchiectasis after resection on the first side is about as uneventful as in the unilateral cases Much of the trouble encountered in the early developmental period of the surgical treatment of bronchiectasis was due to failure to excise all diseased segments Frequently the left lower lobe was excised without removing a diseased lingula This remaining diseased segment initiated difficulties with other segments It served as a reservoir of infection and often led

to suppurative disease elsewhere, usually in the ipsolateral segments Also, re expansion of the upper lobe brought about a shift in the position of the lingular branches so that drain age from this segment was seriously interfered with Present day technique calls for eradication of all the affected unilateral segments at one operation Basal segments and lingular segments are resected with conservation of the superior segments of the lower lobe

Post operative contralateral spread of disease following pulmonary resection for tuberculosis still constitutes a hazard that has not been entirely eliminated Much has been done, however, to successfully reduce the incidence of this complication, such as the prone position used during opera tion, local anesthesia, and early temporary ligation of the bronchus in the course of the dissection of the lung

Should a pneumonia or pneumonitis develop in any case following resection all medical measures known to be of value can be instituted The offending bacterial organism should be known The most effective chemotherapeutic drug or antibiotic can then be employed Oxygen therapy and other supportive measures can be used

Chapter VII

Post-Resection Thoracoplasty

FOLLOWING the extirpation of varying amounts of lung tissue, the remaining thoracic viscera undergo certain changes in their position and volume. There are two important factors which enter into consideration of the post-resection state. These are the age of the subject and the extent of the resection.

The experimental work of Hilber and of Bremer has established the fact that hyperplasia of lung tissue does occur if an increase in lung volume is called for before the end of the growth period. A true increase in the number of atrial units takes place (growth) after a preliminary distention of existing units (compensatory emphysema). Hilber reported that in rats after partial lung removal there is a gradual *replacement by true regeneration of normal* lung tissue. This is accomplished by new growth, and entails an increase in the number of the respiratory units maintaining new alveoli of normal size and structure, an actual remodeling of the bronchial tree. Bremer studied a cat and a five-weeks-old kitten *a month after their right* lungs had been removed. In the adult animal, the remaining specimen was greatly enlarged, this being due to simple distention of alveoli. In the kitten, the alveoli were of normal size indicating an increase in their number. Further proof of the regenerative growth of the *immature* lung was shown by the presence of a greater number of tubular sprouts than would be seen ordinarily in a specimen of that age.

Children and adolescents tolerate total pneumonectomy or bilateral lobectomy extremely well and adjustments to pulmonary tissue loss take place automatically. The mediastinal

structures are highly mobile and the chest wall itself responds to some volume change The hemithoracic space may become obliterated by all boundaries (the mediastinum, the diaphragm, and the chest wall) moving in their relative positions The resiliency of the remaining lung in the young immediately permits safe compensatory emphysema and an extensive mediastinal shift Later, the remaining lung undergoes true hyperplasia and the individual continues with virtually a normal development Therefore, in children or adolescents, resection can be applied in the treatment of pulmonary disease without the necessity of further surgical intervention for the purpose of correcting for volume loss

In adults, the adjustment that follows resection may require such extensive over stretching of remaining pulmonary tissue that a pathological degree of emphysema is inevitable This applies particularly to two groups, those treated for cancer and for tuberculosis Both age and extent of resection are causes for difficulty in cancer patients A total resection is demanded in all curative types of resection The remaining lung in a person past middle age has already lost some of its elasticity, and the ribs and cartilages of the thoracic cage are more fixed

Post pneumonectomy patients past middle age, both with and without a supplementary thoracoplasty have been observed over periods varying up to thirteen years Earlier in our experience only those patients who developed an empyema were subjected to thoracoplasty as this was necessary to obliterate the space Those patients have maintained a state of good health without any evidence of cardio-respiratory embarrassment The uncomplicated earlier resections were not treated by thoracoplasty and the early months of their post operative period were traversed uneventfully The hemithoracic space soon filled with a sero fibrinous clot which became an adequate space occupying material for quite some time Later on however, with fibr[illegible] tissue organization and contraction mechanical fac[illegible] were brought into play which were deleterious Patien[illegible] were more conscious of a heaviness or discomfort in the c[illegible] me [illegible] and

some developed vague pains months after resection Dyspnea and palpitation were noted by some and tachycardia was a frequent finding X-ray substantiated the presumption that a marked mediastinal shift had occurred with related changes. The trachea showed marked angulation The heart was displaced and rotated The contralateral lung field revealed decreased density with fewer lung markings Anteriorly, extensive herniation of the lung to the side of resection had developed It seemed reasonable to assume that the delayed symptoms were related to the delayed mechanical stress and strain imposed upon the remaining thoracic viscera Readjustment of the position of the thoracic wall was proposed as a treatment A modified thoracoplasty was carried out as a delayed procedure In most instances relief of symptoms and improvement in the state of health followed.

The second group of patients in whom particular attention must be given to retailoring the thoracic cage to conform to a reduced lung volume is the tuberculous group. In these patients apparently healthy and functioning segments may have been previously seeded with disease. Over-distention of pulmonary tissue predisposes to activation of foci which otherwise would continue to remain dormant. The late follow-up of resection cases in our tuberculous group has shown an incidence of re-activation three times as high in those not protected by a supplementary thoracoplasty

In younger individuals volume adjustment following lower lobectomy in tuberculosis can usually be met by permanent diaphragmatic paralysis However, in certain patients with long-standing disease, phrenic paralysis alone has not sufficiently prevented over-distention and avoided re-activation Therefore the reduced thoracic volume provided by thoracoplasty should be given consideration in protecting the remaining ipsolateral lung after lower as well as upper lobectomy.

Longacre, Carter, and Quill, experimenting with dogs, attempted to evaluate the degree of cardio-respiratory impairment following total pneumonectomy, and to assay the degree to which the animals could in time achieve a func-

tional adaptation to the anatomical removal of approximately 50 per cent of their pulmonary tissue The authors studied the physiological response in healthy young dogs to varied amounts of moderate and severe strain The same animals were pneumonectomized two months later, and then, at monthly intervals for three more tests, the studies were repeated An adequate cardio respiratory reserve for resting conditions and for moderate exercise was found After severe exercise the animals showed an elevation of pulse and respiration, associated with a marked unsaturation of the arterial blood The authors reported that on succeeding studies months later there was a tendency for the animals to show increasingly less embarrassment The increase in the tidal air tended to diminish the difference of the oxygen tension between that of the atmospheric air and alveolar air They also stated that the increased subtidal lung volume (residual air) may increase the functional diffusing area of the lungs and that the steady increase in hemoglobin bespeaks more effective carriage of the oxygen to the tissues with a tendency for the blood returning to the lungs to be less unsaturated

Most interesting, however, are the studies of Cournand and Berry of various physiological problems arising as a result of pneumonectomy performed on adults Their studies were based on pre and post operative data concerning twelve patients between 23 and 64 years of age, on whom pneumonectomy was performed The following functional studies and measurements were made lung volume and subdivisions, maximum breathing capacity, ventilation, breathing reserve, and respiratory gas exchange The state of respiratory gases in the arterial blood and variations in venous pressure, circulation time, and vital capacity following an increase in blood volume studies were made under basal conditions, during moderate exercises and during a five minute period of recovery following exercise In four of the patients studied, pneumonectomy was supplemented by a thoracoplasty, and in two of these functional measurements were made before and after pneumonectomy and again after thoracoplasty The breathing reserve under vary

ing conditions of activity was lower than in normal subjects and the tendency to dyspnea was greater. The reduction of ventilatory efficiency was not proportional to the loss in lung volume and to a considerable extent depended upon the degree of pulmonary distention Lung volume measurements failed to reveal evidence of developing emphysema when the mediastinum was maintained in its normal position. In one of these patients following pneumonectomy the maximum breathing capacity was reduced to about 50 per cent of the pre-operative pneumonectomy value, and the alveolar ventilation was apparently less efficient in supplying oxygen for tissue needs The authors thought that the unfavorable functional result was due to moderate over-distention of the remaining lung as successive measurements had shown a steady increase of the percentage of residual air in the total capacity A thoracoplasty was then performed and one month after its completion the percentage of residual air in the total capacity returned to the pre-pneumonectomy level, and the breathing capacity was nearly 20 liters larger than before thoracoplasty Their conclusions tend to show that thoracoplasty does not reduce further the ventilatory function if measures are taken to keep the spine straight, preserving the maximum expansion of the chest bellows on the unoperated side Post-thoracoplasty scoliosis may be highly detrimental to the mechanical efficiency of the chest bellows.

The maintenance of the normal position of the mediastinum is an important factor in preventing over-distention of the remaining lung If this structure and its contents can be kept in the natural midline position, the remaining lung will not be called upon to increase in size Air or oil is sometimes used in the pleural space to maintain the midline position of the mediastinum Pneumo- or oleothorax should be instituted early in the post-operative course before the pleural fluid is replaced by fibrous tissue The practice of pneumothorax entails repeated refills that may be necessary to carry on indefinitely Oleothorax has also been used as a more permanent means of controlling the position of the mediastinum It is usually well tolerated by the patient It should be kept

are disturbed and function is reduced. These objections can be met, however, by carrying out a modified type of thoracoplasty without disturbing the first rib, the transverse processes, and the ligaments attaching to them Post-operative scoliosis is prevented and the movements of the contralateral thoracic cage are not compromised In fact, the impairment of thoracic movement is less than that resulting from the contraction of a fibrothorax

GENERAL PRINCIPLES OF POST-RESECTION THORACOPLASTY

The plastic procedure which molds the thoracic cage after resection has as its sole objective thoracic volume reduction Specific cavity obliteration is not required This is fortunate for the thoracic wall may be shifted without disturbance of cervical or thoracic vertebral supports The upper thoracic aperture can be preserved The attachments of the scalene and serratus muscles need not be detached from the first rib or from the periosteum and muscle bundles below The first rib is not resected The transverse processes are not disturbed In this way cervical and thoracic scoliosis does not develop In fact there is no obvious deformity or functional impairment of arm or shoulder motion

The extent of the thoracoplasty can be varied somewhat according to the age of the patient, the shape of the chest, and the appearance of the post-resection x-ray.

Since the remaining lung herniates across the anterior mediastinum, the upper anterior chest wall should be shifted in position as well as the lateral and posterior walls The optimum interval after resection is determined by the condition of the patient, the hardening of the non-osseous tissues of the chest wall, and regeneration of bone at the site of the previous thoracotomy Six weeks has proved to be the most propitious time for the average patient

First Stage Post-Pneumonectomy Thoracoplasty— This stage consists of an anterolateral operation with removal of the anterior half of the second, third, and fourth

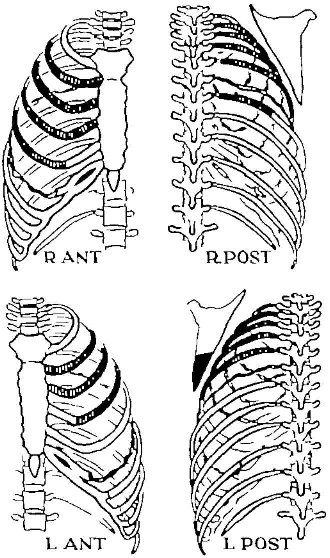


FIG. 65 Drawings of thoracic cage illustrating the extent of the modified type of thoracoplasty which is carried out as a delayed procedure after pneumonectomy The length and number of ribs and cartilages which are to be subperiosteally resected are indicated by dark lines.

Left upper drawing (R. Ant) The plan of the first stage for right-sided cases. An anterolateral incision is used Note that all of cartilages 2 3 and 4 are removed to permit adequate retraction in this area. This is necessary to prevent undue anterior herniation of the left lung into the right chest

Right upper drawing (R. Post.) The extent and number of ribs to be removed at the second and final stage on the right side. Note that the first rib has not been removed and all transverse processes remain intact The posterolateral scar (pneumonectomy) is excised at this time

Left lower drawing (L. Ant) The plan of the first stage for left sided cases. An anterolateral incision is used

Right lower drawing (L Post) The extent and number of ribs to be removed at the second and final stage on the left side. Note that the tip of the scapula has been removed to prevent its impingement on the uneven thoracic cage below This step is not always required

ribs, and the second and third cartilages On the right side, the anterior third of the fifth rib is resected (see Figure 65 [R. Ant.]) Local anesthesia is used The incision is made in the anterior axillary line and carried down just lateral to the pectoralis major muscle This muscle is then lifted up to expose the pectoralis minor, and the loose areolar tissue between the two muscles is separated The pectoralis minor muscle need not be disturbed. The cartilages and ribs come into view and can be readily resected. Perichondrial and periosteal elements are carefully preserved.

Second Stage Post-Pneumonectomy Thoracoplasty—The second and final stage is performed ten to fourteen days after the anterolateral operation Local and paravertebral block anesthesia is again used The posterior half of the resection scar is excised The posterior segments of the second, third, and fourth ribs, and the posterior half of the fifth rib are resected subperiosteally (see Figure 65 [R Post]) The sixth rib has already been resected at the exposure for the resection If the tip of the scapula impinges upon the seventh rib, a short segment of this rib is removed The transverse processes and the first rib are left intact No attempt is made to detach the serratus magnus muscle from periosteal elements so that its anchorage to the newly formed chest wall will be secure

We have found that there are many advantages in doing the post-pneumonectomy thoracoplasty in two stages first, the complete removal of the second, third, and fourth ribs and cartilages is greatly simplified; second, it is possible to do the first stage sooner in the postoperative course, and third, the operative interference does not retard convalescence from the resection itself In right pneumonectomy cases we routinely sever the phrenic nerve during the resection On the left this is not done because it predisposes to troublesome gastric disturbances in some cases.

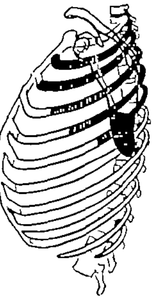


FIG. 66 Drawing of the lateral aspect of the thoracic cage illustrating the modified type of thoracoplasty carried out as a delayed procedure following lobectomy for tuberculosis. The extent of the subperiosteal rib and cartilage resection has been indicated by dark lines Note that the first rib is not removed. The transverse processes are also left intact. The tip of the scapula is removed if it is found to impinge on the first unresected rib The extent of the scapular resection has been also indicated by dark lines.

POST LOBECTOMY THORACOPLASTY FOR TUBERCULOUS SUBJECTS

Following lobectomy the compensatory mechanism that takes place in the remaining lobes is directly related to the size of the resected lobe or lobes In the event that the lobe to be removed is small and contracted from fibrotic changes, the ipsolateral lobe has already acquired the necessary volume to occupy the entire hemithoracic space In these cases, post operative adjustments are minimal The distention of the ipsolateral lobe is only slightly increased, the diaphragm may ascend a little, but there is little or no mediastinal shift However, following the extirpation of a normal sized lobe, the obliteration of the pleural space calls for considerable volume change in both ipsolateral lobe and contralateral lung

In tuberculous subjects the tissue which remains may have stretched beyond its original volume This condition should

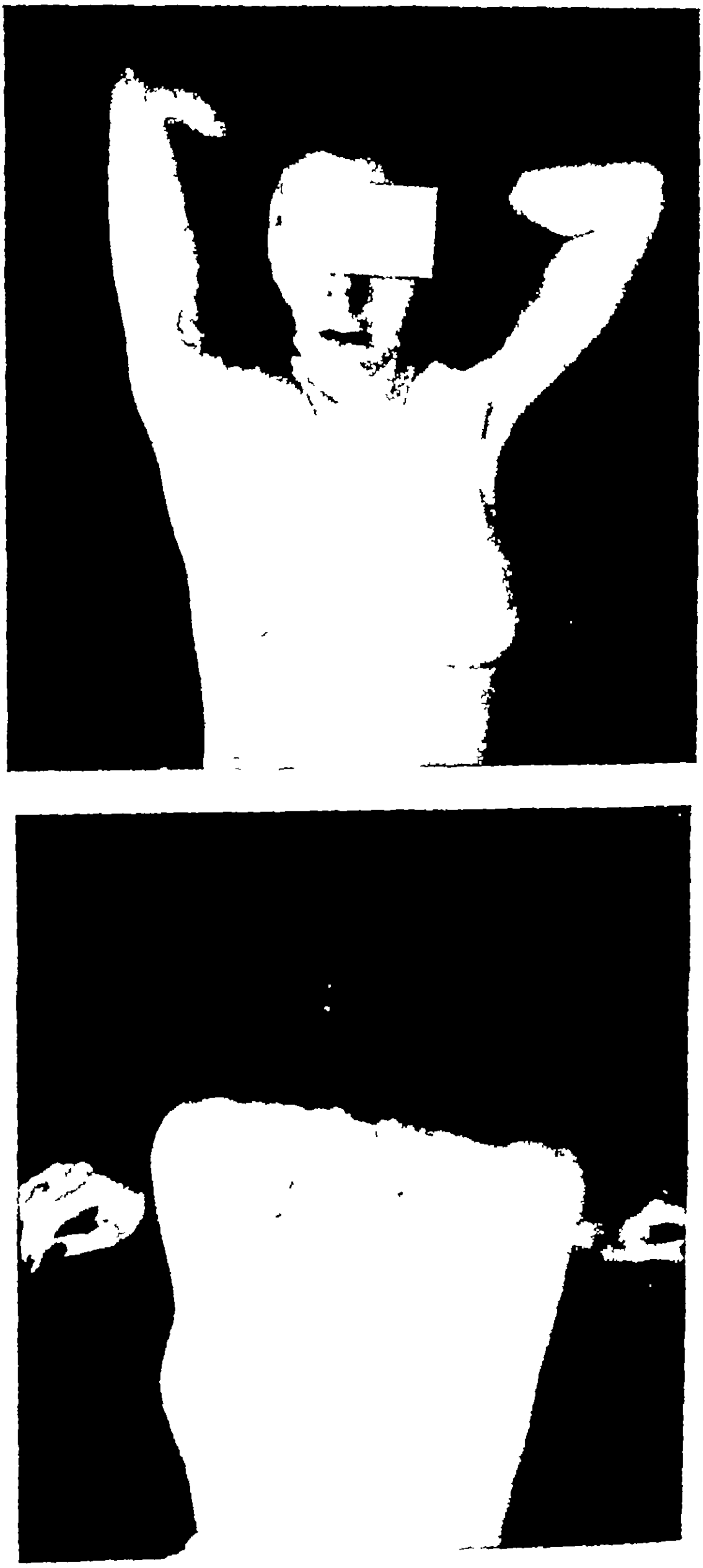


Figure 67

be corrected in planning the thoracoplasty The chest should be remodeled so that its final volume will be no larger than the volume of the remaining healthy lung as it existed prior to the development of the disease

One Stage Thoracoplasty—This operation is done four to six weeks after lobectomy It is performed under local anesthesia The previous posterolateral incision is excised The second and third ribs are resected completely including their cartilages The posterior two-thirds of the fourth and

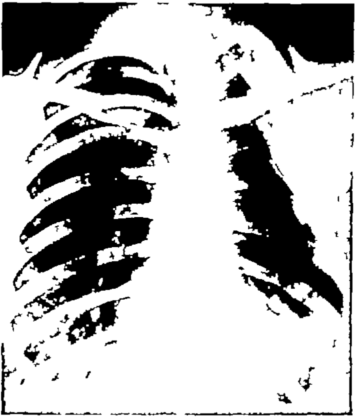


FIGURE 68

FIG. 67 Photographs of patient after upper lobectomy and modified thoracoplasty Note lack of deformity and full range of shoulder motion This patient has been treated by primary lobectomy for extensive tuberculosis of the left upper lobe

FIG. 68 Roentgenogram of patient in Figure 67 Note support given by first rib transverse processes and osseous regeneration *Also note ventilating area of lower lobe.*

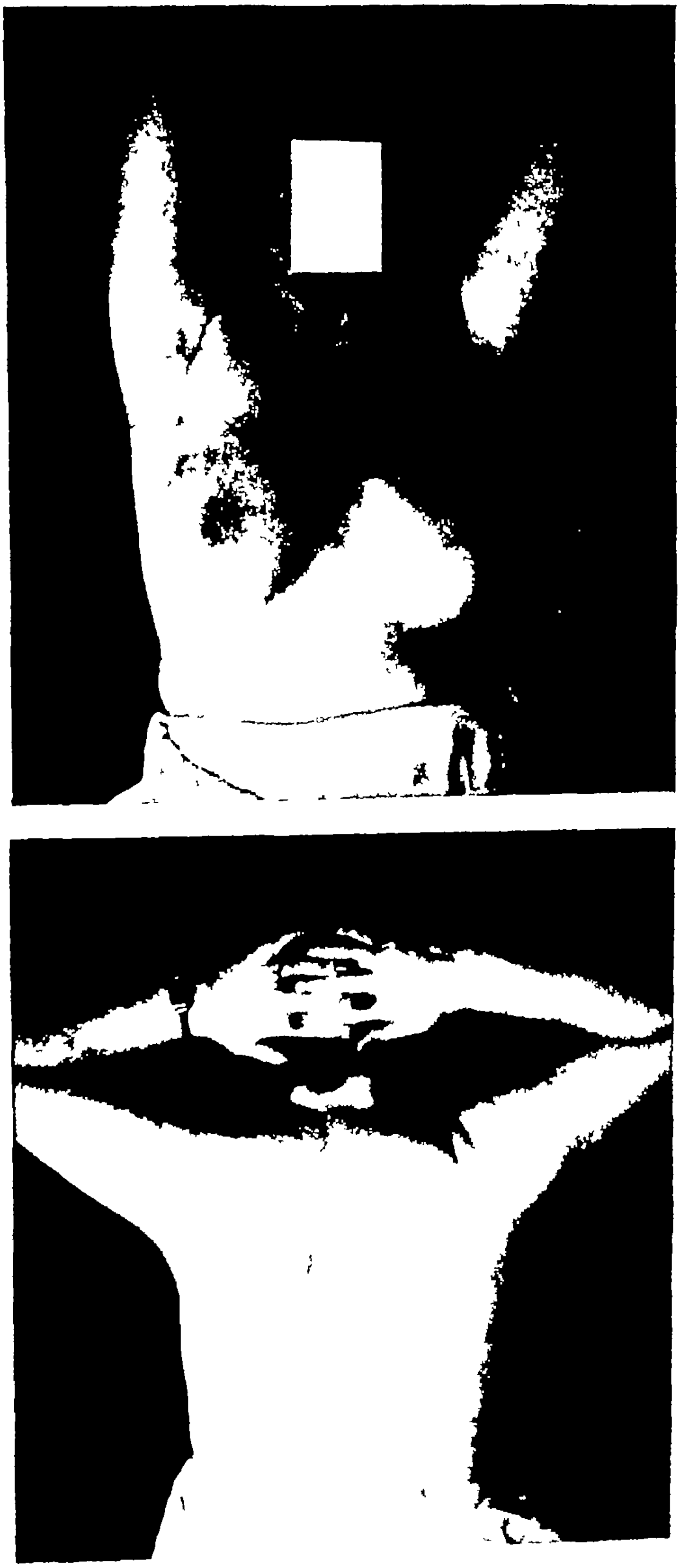


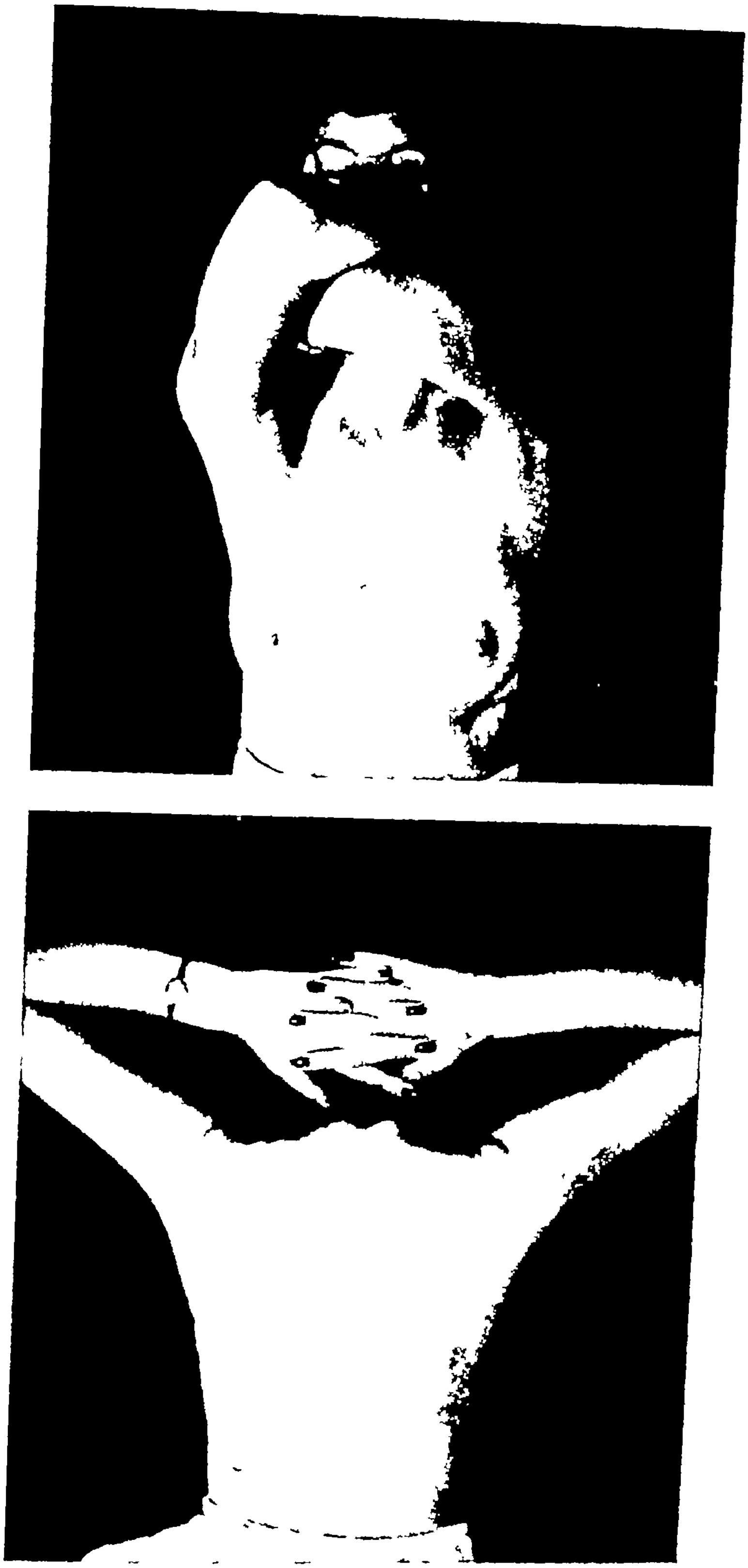
FIGURE 69

fifth ribs and the posterior half of the sixth rib are removed The first rib and the transverse processes are left intact. A partial scapulectomy is done if the tip of the scapula is found to impinge on the ribs below (see Figure 66) The removal of the lower tip of the scapula prevents an upward and for ward displacement of the shoulder Deformity can be en tirely prevented if the scapula fits comfortably to the new contour of the thoracic cage

FIGURE 70

FIG. 69 Photographs of patient after modified two-stage post pneumonec tomy thoracoplasty illustrating full range of shoulder motion and lack of deformity The left lung was removed because of extensive parenchymal and bronchial tuberculosis.

FIG. 70 Roentgenogram of patient in Figure 69 The intact first rib and transverse processes on the left show clearly Note position of trachea, normal densities of lung markings on right (absence of emphysema) - and minimal curvature of vertebra.



71 Photographs of patient after treatment for bilateral bronchiectasis
ionths previously the left basal and lingular segments were removed
2 months previously the right middle lobe and the right basal segments
removed Note lack of deformity and full range of arm and shoulder
n

Afterword

THE AUTHORS predicted in the Foreword that certain details of procedure would have been discarded and others added by the time of publication This has happened but to a lesser extent than anticipated Present day practices which are at variance with those advocated when the manuscript was submitted in January of 1947 should be brought to the reader's attention

1 The use of pneumothorax as one phase of the preparation for selected cases of pneumonectomy has been discontinued (p 8) Recent experience has shown that the antibiotics are so effective in improving the general condition of patients that the preparatory period may be simplified and shortened Many of the conditions which a gradual deflation of the lung by pneumothorax favorably influenced,—cough, bronchial secretions, and absorption of toxic substances from the lung, are more easily and favorably controlled by the antibiotics

2 Aerosol methods of administering the antibiotics are rarely used now (p 4) For prophylaxis, a 24 to 48 hour administration of penicillin and streptomycin is usually given intramuscularly In some cases, one of the drugs which may be administered orally (chloromycetin, aureomycin or terramycin) is given When an infection exists prior to surgery, a longer preparation with appropriate drugs is carried out

3 An arm vein is usually satisfactory for infusions during the operation instead of the saphenous vein (p 10) This change has been made to avoid a chemical or traumatic phlebitis which occasionally resulted when the saphenous vein was used for venoclysis

4 Diagnostic bronchoscopy in many cases is carried out immediately preceding the introduction of the intratracheal tube (p 16) When a lung resection is indicated, regardless of whether the bronchoscopic findings will be positive or

negative, this instrumentation can be done just as well when the patient is being prepared for the intratracheal intubation. It saves time for the surgeon, the patient, and the hospital personnel, besides sparing the patient extra discomfort and cost.

5 Instruments (p 26) The use of a double-bladed knife has been abandoned In stage operations, scars are excised, but a single knife is just as serviceable The rib-spreading retractor (Finochietto) has been modified The shafts of the blades have been curved to conform to the chest-wall curvature, and the cross-arm has been lengthened (Codman & Shurtleff, Inc, 104 Brookline Avenue, Boston, Massachusetts).

6. In the opening, no ribs are resected (p 31). The full length of the 6th rib is denuded of its periosteum and cut in but one site only (about 1 cm from the transverse process) This rib is then displaced to one side and an incision made in its periosteal bed. If ribs above and below the 6th require division, these ribs are divided, but a segment of rib is not removed (See Figure 11a and Figure 13)

7. An intercostal incision for exploration, lobectomy or segmental resection has been abandoned (p. 33). It is impossible to re-approximate securely the pleura and intercostal muscle During acts of coughing or strain, the lung may herniate into weak points between the ribs A periosteal bed provides firm tissue, the parallel lateral portions of which can be securely sutured. The rib displacement and replacement method is used as a standard procedure for all intrathoracic operations.

8 Exposure (p 35). In the event of empyema, tuberculous or otherwise, the endothoracic fascia and parietal pleura are not incised as the ribs are spread This facilitates the extrafascial enucleation of the walls of the empyema space Often, the membrane which forms the walls of the closed sac can be removed intact with the lung In many instances, when a pulmonary resection is indicated in the presence of an empyema, not all of the lung requires removal This situation is more frequently encountered in tuberculous subjects

with pleural complications following long periods of pneu mothorax In this event, it is usually impossible to enucleate the membrane as a complete sac After the separation of the parietal portion of the membrane, only that portion of the membrane which overlies normal lung is removed It is rarely possible to peel the membrane from the surface of un derlying diseased segments It is necessary, therefore, to open the sac on the visceral side at the line of demarcation between the segments which are to be removed and those which are to remain

9 Exposure (p 35) In the dissection of an empyema or pneumothorax membrane, it is important to remember that its reflexion does not correspond to the reflexion of the pleura It makes its posterior turn more laterally than the pleura One must guard against carrying the dissection into the retro aortic space on the left or esophageal area on the right. In the former instance, unnecessary ligation of inter costal arteries is avoided and, in the latter, injury to the esophagus itself is avoided Either structure may be greatly displaced by the contraction of a diseased lung, empyema wall or pneumothorax membrane

10 The importance of liberating all segments (except in cancer cases) that might be sound or capable of function was not sufficiently emphasized in the text (p 35) The lung should be completely mobilized, all healthy segments which are covered by a membrane decorticated, and the pulmonary ligament divided These steps are taken for the following reasons

(1) In planning the extent of the resection, it is neces sary to inspect, palpate and test the inflation and deflation of any segments that are not to be included in the resection Surface membranes which constrict segments prevent a satisfactory appraisal of the soundness of the various segments

(2) When the lung is liberated the dissection and con trol of the structures of the hilum is facilitated

(3) Recovery of maximum function, full re expansion and the immediate obliteration of the pleural space

are favored The division of the pulmonary ligament in upper segmental or lobar resections is particularly important, for the basal segments are then free to move upward This insures obliteration of a space above the remaining lung

11. Wedge resection for purposes of biopsy and for isolated tuberculous nodules (p. 37–39). Small lesions situated in the fringe of a lobe or near its surface may often be removed in their entirety by simple wedge excision. In performing a wedge resection, the following procedure has been adopted:

(1) Inflate the lobe with moderate pressure when clamps are applied There is great danger of including too much normal adjacent parenchyma if the pulmonary tissue is concentrated by deflation

(2) Use a fine, light clamp, preferably a straight mosquito hemostat

(3) Use interlocking, interrupted mattress sutures (silk 3–0 with atraumatic needle)

(4) Apply only one clamp at a time on the side to be sutured Place a single or double mattress suture, tie, and remove the clamp before the next application of the clamp

12 Sequence of dissection and treatment of vascular structures (p 47) The artery is usually treated first, then the vein and then the bronchus When, however, the fissure is absent or densely fused, it may be necessary to reverse this order and treat the vein, the bronchus and then the artery in that order Also, in segmental resection, it is often expedient to find the segmental artery, then the bronchus and finally the central vein Since the anatomy presented is subject to variation and the pathologic process never constant, dissection procedure cannot be stereotyped

13 Closure of major bronchi (p 51–57). The method previously described and illustrated (Figure 17a-h) has been abandoned In Figure 171 is shown the general plan of bronchial closure which is now used The steps are, as follows:

(1) Prepare the bronchus for as high an amputation as possible

(2) Use a bronchial clamp only on the distal side of the line of incision This avoids trauma to the area of suture

(3) Incise the bronchus only through its posterior two thirds at first and use the lung and distal bronchus for traction

(4) Aspirate secretions from the interior of the open bronchus

(5) Incise the last two rings of cartilage in their mid or anterior portion from within This permits the walls of the bronchus to be approximated without tension on the sutures

(6) The membranous portion is invaginated by the first suture to be placed which becomes the central end suture, only two others being required This first suture is placed around the mid portion of the terminal half cartilage on one side, gathers up the membranous portion, then passes around the last cartilage on the opposite side When it is drawn taut and the knot slid into position, the two half cartilages come together with the membranous portion plugging the posterior portion This tends to invaginate the end and reduces the cut surface to one half the diameter of the transected bronchus

(7) All mattress sutures have been abandoned

(8) Free pleural or fascial grafts for bronchial stump covering have been abandoned Also, flaps of mediastinal pleura have been found to be unnecessary In pneumonectomy, the short stump retracts and disappears within the tissues of the mediastinum and automatically becomes buried in living tissue The placement of sutures in the peribronchial tissue is avoided, for it serves only to interfere with blood supply of this area After lobectomy or segmental resection, the re expanded lung immediately fills

are favored. The division of the pulmonary ligament in upper segmental or lobar resections is particularly important, for the basal segments are then free to move upward This insures obliteration of a space above the remaining lung

11 Wedge resection for purposes of biopsy and for isolated tuberculous nodules (p. 37–39) Small lesions situated in the fringe of a lobe or near its surface may often be removed in their entirety by simple wedge excision. In performing a wedge resection, the following procedure has been adopted ·

(1) Inflate the lobe with moderate pressure when clamps are applied There is great danger of including too much normal adjacent parenchyma if the pulmonary tissue is concentrated by deflation

(2) Use a fine, light clamp, preferably a straight mosquito hemostat.

(3) Use interlocking, interrupted mattress sutures (silk 3–0 with atraumatic needle)

(4) Apply only one clamp at a time on the side to be sutured Place a single or double mattress suture, tie, and remove the clamp before the next application of the clamp

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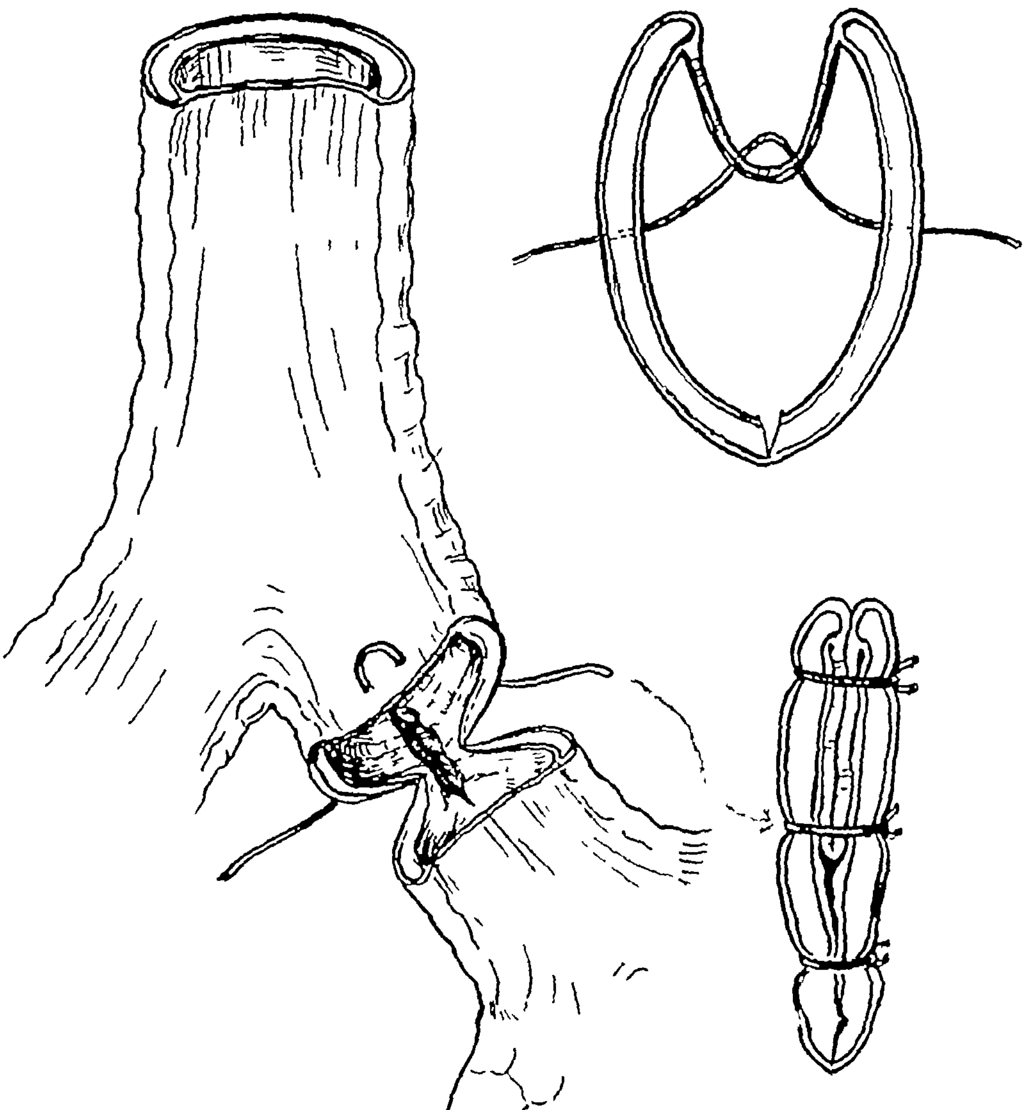
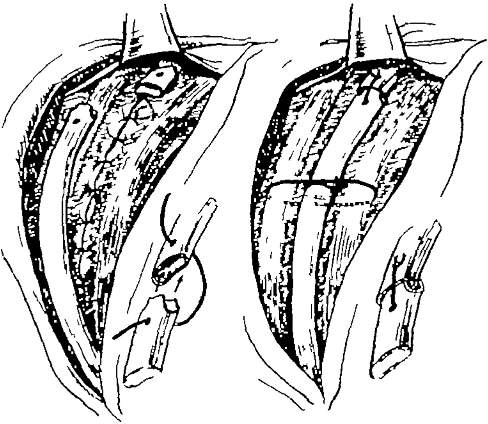
and obliterates the pleural space, thus bringing living tissue over the bronchial end.

(9) Stainless-steel wire sutures, formerly advocated in the closure of the bronchus when its wall was involved in tuberculous disease, have been abandoned. Fine silk, size 3–0, with an atraumatic needle is preferred for bronchial closures in all cases.



14 Closure (p 59–62). The previously denuded rib, which had only been cut posteriorly, is swung back to its original position after the periosteal bed has been closed with interrupted silk sutures The ends of the rib are firmly

re united by a mortise and tenon union and held there by two silk (#2) sutures passed through drill holes On the pos terior rib end, the marrow is curetted out and this hollow becomes the mortise The tenon is formed on the opposing rib end With a small rongeur, a small bite each side of the end of the rib is taken and the marrow between the inner and outer lips is then removed The outer lip becomes the



tenon and the inner lip overlaps the under surface of the opposed rid end Neither the mortise nor tenon need be greater than 2–3 mm. in length, and the strength of the union will be proportionate to the tightness of the fit When the final fitting is ready for fixation, a bone holder applied to the rib end aids in jamming the joint firmly together The union can be made practically as firm as an uncut rib and more stable than when intermedullary pegs are used Stable reunion of deliberately severed ribs has an advantage over uncut ribs disrupted from their vertebral attachment or frac

tured by a rib spreader At the final union, there need not be any lateral displacement There is, of course, an offset on the outer surface equal to the width of the cortex of the rib—about 1 mm It is difficult or impossible to find the point of union in the post-operative film In the event that ribs have been divided above or below the one used for displacement, they are reunited as described above It is possible to provide ample exposure for any type of intrathoracic procedure since this method insures that all ribs cut for exposure are re-aligned and solidly fixed in their original position In the event of a large tumor, a densely adherent lung, or an un-yielding chest wall due to long-standing inflammatory reaction, the division of three to five ribs posteriorly may be expedient Regardless of the number of ribs divided, the firm reuniting of their ends may be accomplished and the stability of the chest wall maintained Patients have far less discomfort with this method of incision and closure than with any other method we have used

15 Closure (p 62) Stainless-steel clips as pericostal supports have been abandoned.

16 Drainage after pneumonectomy (p 63) A single catheter is inserted in the pleural space in all pneumonectomy cases It facilitates (a) pressure readings; (b) removal of fluid or air; and (c) instillation of antibiotics During the closure, the tube is connected to an underwater seal This automatically regulates the pressure until the patient is back in bed When the patient is turned from the face-down or lateral position to his back a great shift in the volume of the hemithoracic space occurs due to changing positions of its boundaries (largely diaphragmatic shift) Intrapleural pressures within the closed space, therefore, are subject to marked alterations It is extremely important to provide a continuous exit for air as the patient is turned A catheter closed by a water seal prevents any build-up of intrapleural pressure as the shift in the body position takes place This method of automatic pressure adjustment does away with the necessity of introducing a needle to check manometer readings after wound closure and after the patient is shifted to his bed

17 Drainage after subtotal resection or thoracotomy (p 63–64) Following segmental resection or whenever there is any possibility of an air leak from the lung surface (for example, after decortication), two drainage tubes are used The tubes are placed intrapleurally prior to the reconstruction of the thoracic wall The first is inserted in the third or fourth interspace (mid axillary line beneath the elevated scapula) and its tip directed to the pleural dome The second is inserted in the 7th interspace and its tip directed posteriorly and inferiorly Both tubes are carried out the anterior angle of the wound It is important to provide doubly for the escape of fluid or air from the pleural space during the process of re expansion A single tube may become occluded Also, uneven re expansion of the lung may form separated compartments, trapping air or fluid, which a single tube would not drain

18 Massage of the heart (p 69 and 70) We do not wait for the heart to stop before using this valuable method to augment its action and preserve adequate coronary blood flow Whenever (a) the color of the blood indicates poor oxygenation, (b) the heart rate becomes slow and its action is noticeably feeble, or (c) the blood pressure drops under 80 systolic and does not immediately respond to the usual supportative measures, the heart is manually compressed in a rhythmical manner until its action becomes more vigorous Everything said about emergency situations on pages 66–72 is still good advice, however the earlier employment of cardiac massage when the first sign of an embarrassment in circulation is noted will do more to help re establish normalcy than the use of any drug

19 Left anterior segmental artery (p 92) It has been emphasized that there is great variation in the arrangement of the segmental arteries particularly of the upper lobes It was implied in the original text that the left anterior segmental artery takes origin most frequently from the interlobar aspect of the main trunk This is not the case, for its most common origin is an anterior one, with a take off above the postero apical bronchus and then the vessel descends in

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front of this segmental bronchus to enter the anterior segment from that direction *

20 The lingular and middle-lobe veins (p. 94–98) Occasionally, the lingular vein has been found to be divorced from the superior vein and to join the inferior vein or enter the auricle separately The same variation has been found on the right side in respect to the middle-lobe vein.

21 Development of the intersegmental plane (p. 143–144) A useful maneuver recently discovered and employed is most helpful in starting the separation of the intersegmental surfaces. After the segmental bronchus, artery and central vein have been divided, the adjacent segments are inflated Previously, the segment to be enucleated was turned back upon itself, but this tends to fold the bronchi as they approach the intersegmental plane Instead, the divided bronchus is placed under tension toward the hilum as a finger is inserted close to the cut bronchus and gently pushed through to the periphery. The finger finds the plane easily, for it follows the path of least resistance. When the pleura is reached, it is incised over the finger The finger is then reintroduced from within and brought out in two or three more places and the pleura opened again Then, with a finger of one hand working from the inner aspect and one from the other hand introduced through these pleural openings, it is possible to rapidly develop the intervening portions of the intersegmental plane If this type of dissection is done with extreme care, small venous branches of the intersegmental vein will not be torn They may be clamped then with mosquito hemostats and divided under direct vision The majority of the intercommunicating veins arch between the segments near the periphery of the plane and can be easily felt and seen in the process of separating the segments

22 Postoperative care (p. 161). Tracheotomy with a temporary tracheal cannula may be necessary if the airways cannot be adequately kept open otherwise When patients have great difficulty in raising secretions and intratracheal

* I am indebted to Dr M C A Klinkenbergh and Dr A G Brom, of the University of Utrecht, Holland, for calling to my attention this error

aspiration via a tube introduced through the nose or bronchoscopy are difficult to carry out frequently, then tracheotomy should be done In our experience, however, this device to remove tracheal and bronchial secretions is rarely necessary

23 The pleural catheter placed after pneumonectomy is opened and the pressures tested every six to eight hours (p 161) Patency of the tube is easily determined by watching the action of liquid in the tube If a positive pressure has built up during the interval that the tube is clamped, the excess of air or liquid soon runs off when it is unclamped On rare occasions, an abnormally high negative pressure will be found and an injection of air will be necessary to adjust the pressure Antibiotic drugs, in solution, are instilled via the tube. In uncontaminated cases, it has been our practice to use 200,000 units of penicillin and 1 gram of streptomycin daily In contaminated cases, the dosage is varied according to the type of organism, as determined by culture, and to its sensitivity The catheter is withdrawn in four to five days in most cases, for by that time pressures have been stabilized, fluid has stopped forming and an adequate period of administration of the antibiotic drugs has elapsed Drainage tubes are stripped by nurses and assistants regularly in order to favor the maintenance of their patency This is done by compressing the walls of the tube between the thumb and forefinger and by stroking, using a lubricating jelly to reduce friction

24 The temporary maintenance of pneumoperitoneum in the early postoperative period may aid in space obliteration after partial lung resection (p 162) When remaining pulmonary segments do not comfortably expand to fill the hemithorax, this method of space reduction is effective and safe Air beneath the diaphragm does not lessen the effectiveness of cough as has been noted with temporary phrenic paralysis

25 Post resection thoracoplasty (p 180–185) In many patients, it is possible to execute a thoracoplasty at the time of the resection A small thoracoplasty can almost always be done simultaneously if the resection is a limited one Follow

ing pneumonectomy, it is also possible to reduce adequately the thoracic volume at the time of the resection if (1) the patient's general condition and reserve was good prior to surgery; (2) the resection was not a complicated one; (3) there was no undue contamination; and (4) the patient's condition is found to be satisfactory at the conclusion of the resection The simultaneous thoracoplasty following resection is done in this general manner

1. Short segments are removed from the posterior aspect of ribs 2–5 inclusive, with shorter segments above and larger ones below
2. The lateral plate of the rib cage is then forcibly swung posteriorly so that the lateral ends of the ribs interdigitate with the rib stumps posteriorly The end of the 3rd rib is placed between the 3rd and 4th stumps, the 4th rib between the 4th and 5th stumps and the 5th rib between the 5th and 6th stumps The 6th rib, previously denuded, is also shortened and inserted between the 6th and 7th stumps The ribs are held in this position by two strands of silk, No 2, threaded through drill holes This reduces the lateral diameter of the hemithorax appreciably and provides a wall as intact and unyielding as the normal chest Variations of space reduction are possible by varying the lengths of the segments removed and the number of ribs treated Occasionally, it has seemed wise to shorten the 7th and 8th ribs as well as those above

R.H O , Brookline, Mass
January 18, 1951

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